CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Working Draft Measure Information Template
Light Commercial Unitary HVAC

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team April 2011

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Light Commercial Unitary HVAC

2013 California Building Energy Efficiency Standards

Proposal by: PECI and Taylor Engineering
April 20, 2011

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Acknowledgments

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Overview

Project Title

HVAC Controls & Economizing

Description

This document describes a number of proposed changes to Title 24 that affect controls and economizers:

- Fault Detection and Diagnostics (FDD) is included in 2008 Title 24 as a compliance option. A proposal is to advance FDD as a prescriptive baseline.
- Multipurpose rooms of less than 1000 square feet, and classrooms and conference rooms of any size, shall be equipped with occupant sensor(s) to setup the operating cooling temperature set point and setdown the operating heating temperature set point.
- A thermostat with two stages of cooling is required for single zone systems whenever an outside air economizer is present.
- Revise the prescriptive baseline for economizers from 75,000 Btu/h to 54,000 Btu/h.
- Set the statewide maximum damper leakage at 10 cfm/sf at 1.0 in w.g., to harmonize with the ASHRAE 90.1 damper leakage requirement.
- Mandatory performance features for economizers and revising the current option for RTU manufacturers to apply to the CEC for a certification for a factory installed and calibrated economizer.
- Modify the high limit switch requirements. Previous versions of Title 24 have prescribed air economizer high limit strategies for non-residential buildings based on climate zone. This measure revises the prescriptive requirements and modeling rules for each climate zone based on fundamental psychrometrics, extensive energy simulations, and maintenance and reliability resulting from recently published data regarding humidity sensor accuracy.

Type of Change

These proposed changes include a variety of prescriptive baseline and mandatory requirements as described above for each measure.

Energy Benefits

Detailed energy savings tables are provided in the Appendices for each measure.

With regard to the high limit switch, the current standard allows multiple options for economizer high limits. For the purpose of documenting realistic savings, we have created a baseline that represents a mix of strategies. This measure still allows the designer to choose among multiple strategies within each climate zone, however, the proposed scenario is based on the performance using the recommended fixed drybulb high limit. Savings for each climate zone are based on a prototype building that is a single-story, office building that is 40,000 ft^2. Electricity savings per building and per square foot for each climate zone are provided in Table 1. There are no peak demand savings since economizer operation is during non peak conditions. There are no gas savings. Detailed energy savings tables are provided in the Appendices for each climate zone.

Climate Zone	Electricity Savings (kWh/yr)		TDV Electricity Savings	
	per Prototype Building	per square foot	per Prototype Building	per square foot
CZ1	346	0.009	1,235	0.031
CZ2	667	0.017	1,619	0.040
CZ3	715	0.018	1,738	0.043
CZ4	965	0.024	2,093	0.052
CZ5	605	0.015	1,047	0.026
CZ6	1,651	0.041	4,215	0.105
CZ7	2,001	0.050	7,175	0.179
CZ8	1,687	0.042	3,761	0.094
CZ9	1,082	0.027	2,568	0.064
CZ10	1,009	0.025	1,856	0.046
CZ11	1,161	0.029	5,088	0.127
CZ12	760	0.019	3,065	0.077
CZ13	979	0.024	2,714	0.068
CZ14	1,312	0.033	4,237	0.106
CZ15	1,697	0.042	3,417	0.085
CZ16	313	0.008	967	0.024

Table 1 – Energy Savings Summary

Non-Energy Benefits

Maintenance cost savings will result from the FDD proposal. Improved economizer reliability will result in increased product longevity and reduced maintenance costs. Economizers installed on smaller RTUs and improved economizer reliability will provide higher ventilation rates, which decrease respiratory illnesses and sick leave.

Maintenance costs will be reduced by the elimination of most humidity-based high limit controls. Humidity (and related enthalpy and dewpoint) sensors are very maintenance intensive, requiring recalibration on the order of every 6 months.

Environmental Impact

There are no significant potential adverse environmental impacts of this measure. There may be some small water savings due to reduced evaporation losses for systems that are served by chilled water plants.

Technology Measures

These measures proposed as mandatory requirements utilize technology that is widely available and in widespread use. The FDD proposal is a prescriptive baseline as products are currently available with more anticipated by 2014, however they do not yet enjoy widespread use. Energy savings from these measures will persist for the life of the system.

The most generally applicable and among the most effective high limit controls, the drybulb temperature switch, is one of the most common control devices.

The fixed drybulb + fixed enthalpy high limit control is a newly identified strategy available to any direct digital control system and is available for packaged unit systems with the new Honeywell JADE Economizer Module.

Useful Life, Persistence, and Maintenance:

This measure discourages use of technology (humidity sensors) that has been shown to be unreliable and requires frequent maintenance and recalibration. The analysis incorporates the impact of typical sensor inaccuracy based on claimed performance from leading manufacturers. In reality, published test data show that the humidity sensors do not meet the claimed performance when new, and that performance deteriorates significantly beyond the claimed limits over time. Therefore, the performance degradation of high limit strategies relying on humidity sensors may be conservative in this analysis. Furthermore, widely reported anecdotal evidence suggests that these types of sensors are rarely recalibrated at the frequency recommended by manufacturers so the potential energy impact of the sensor inaccuracy may be much more than shown in this analysis.

This measure either prohibits control strategies that are extremely sensitive to this sensor inaccuracy, or limits the strategies in order to control the impact of sensor bias and drift.

Performance Verification

Additional acceptance testing is required for a number of these proposed measures. Standard commissioning of these systems is also prudent to ensure they are performing as designed.

Cost Effectiveness

These measures are cost effective as described in the Results and Analysis section. Life cycle costs (LCC) were calculated using the California Energy Commission Life Cycle Costing Methodology for each proposed measure. With regard to the high limit switch, this measure saves energy while encouraging the use of fewer sensors, less expensive sensors, and sensors that require less maintenance compared to the previous version of the standard.

Analysis Tools

Some modifications to the performance compliance software programs are likely in order to quantify energy savings and peak demand reductions resulting from the proposed measures.

With regard to the high limit switch, currently available simulation programs such as eQUEST and EnergyPlus are capable of quantifying energy savings and peak electricity demand reductions resulting from the proposed measure. EnergyPlus, however, is not capable of explicitly modeling the sensor error for differential drybulb and differential enthalpy economizer high limit controls.

Relationship to Other Measures

No other measures are impacted by these changes.

Methodology

This section summarizes the methods used to collect data and conduct the analysis for this CASE report for the following proposals:

- Fault Detection and Diagnostics (FDD)
- Occupancy Sensor to Setback Thermostat
- Two-Stage Thermostat
- Economizer Size Threshold
- Economizer Damper Leakage
- Economizer Reliability
- High Limit Switch Performance

Fault Detection and Diagnostics (FDD)

FDD is included in 2008 Title 24 as a compliance option. This proposal is to advance FDD as a prescriptive option.

Numerous HVAC faults were investigated in this study to determine the potential benefit of FDD systems in detecting these faults, including:

1. Air temperature sensor failure/fault
2. High refrigerant charge
3. Low refrigerant charge
4. Compressor short cycling
5. Refrigerant line restrictions/TXV problems
6. Refrigerant line non-condensables
7. Low side HX problem
8. High side HX problem
9. Capacity degradation
10. Efficiency degradation
11. Not economizing when it should
12. Damper not modulating
13. Excess outdoor air

Background and Literature Review / Secondary Data Mining

In this task we conducted a literature review to investigate the current state of the FDD market in terms of current product availability, product development, costs, faults detected, and fault incidence. An annotated bibliography summarizing this literature review is included at the end of this report in the section Bibliography and Other Research.

For the data mining task we relied on PECI's AirCare Plus (ACP) program, which provides incidence data for a number of HVAC faults. ACP is a comprehensive diagnosis and tune-up program for light commercial unitary HVAC equipment between 3 and 60 tons cooling capacity. This program has been active throughout the PG&E service territory since 2006 and throughout the Southern California Edison service territory since 2004. It includes inspection of the following HVAC components: thermostat controls, economizers, refrigerant charge, and airflow. The ACP program database includes over 17,000 RTUs with documented status of these HVAC components. This massive collection of HVAC data proved useful in identifying the incidence of various HVAC faults as described in the Analysis & Results section.

Based on the literature review and data mining, we defined the faults and the associated energy simulations to estimate the savings from detecting and fixing the faults. The remainder of this section provides this information.

Energy Savings

A series of EnergyPro energy simulations and corresponding TDV analysis were conducted to estimate the potential energy savings resulting from use of FDD. A representative sample of California climate zones were modeled, including: 3, 6, 9, 12, 14, and 16. The other California climate zones were not included in these energy simulations as they are sufficiently represented by the selected zones for the purposes of this research. Figure 1 indicates which climate zones the selected zones represent and Figure 2 shows a map of the climate zones.

Simulated climate zone	**Maps to climate zones:**
3	1, 2, 3, 4
6	5, 6, 7
9	8, 9, 10
12	11, 12, 13
14	14, 15
16	16

Figure 1 Climate Zone Mapping

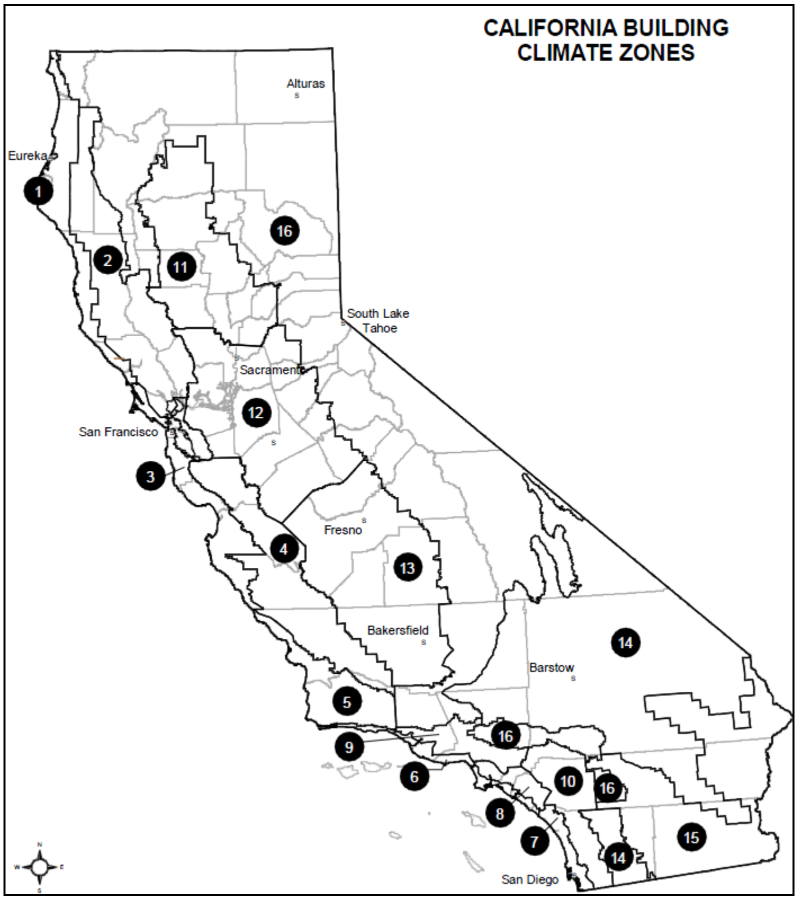


Figure 2 Climate Zone Map

Seven (7) prototype simulation models were developed for the analysis. Figure 3 summarizes a number of key inputs used in the energy simulations:

	Occupancy Type	Area (Square Feet)	Number of Stories	# HVAC Systems	Total tons	Avg sf/ton	Occupancy Schedule
Prototype 1	Fast Food	2,099	1	2	11	199	T-24 schedule
Prototype 2	Grocery	81,980	1	18	249	329	T-24 schedule
Prototype 3	Large Retail	137,465	1	22	286	480	T-24 schedule
Prototype 4	School	44,109	2	39	171	257	T-24 schedule
Prototype 5	Small Office	40,410	2	14	113	356	T-24 schedule
Prototype 6	Small Retail	8,149	1	4	25	330	T-24 schedule
Prototype 7	Large Office	112,270	2	10	421	267	T-24 schedule

Figure 3 Summary of Energy Simulation Models for FDD

Measure Cost

The cost of an FDD system is "*based upon the type of data that is required, the overall number of points required, any processing capabilities that must be added, and communications hardware and access. The principal cost incurred for FDD is for data collection. Depending on the method that is* *used, existing sensors installed in the RTU might be used. Care must be taken to ensure that the sensors are of sufficient accuracy and are installed in the appropriate location. In some cases, redundant sensors might be needed to take the place of the existing sensors.'*'[i]

The CASE authors contacted FDD system developers to identify the measure costs, which are reported in the section Analysis and Results.

Product Availability

There are a few tools currently on the market. A handful of other tools have been piloted but have not yet been introduced to the market as viable products, and yet others are under development. It is useful to describe the tools that are commercially available, available in pilot status only, or in the pipeline. Heinemeier et al. (2010) outlines the development status of various third party FDD systems as shown in Figure 4.

Tool Name	Status	Data	Model	Developer
FDSI Insight V.1	Available	Refrigerant	Quantitative	Field Diagnostics, Inc
Sensus MI	Available	Air	Qualitative	University of Nebraska
ClimaCheck	Available	Refrigerant	Quantitative	ClimaCheck Inc.
SMDS	Pilot	Air	Qualitative	Pacific Northwest National Lab
NILM	Pilot	Power	Qualitative	Massachusetts Institute of Technology
Low Cost NILM	Pilot	Power	Timeseries	Massachusetts Institute of Technology
Sentinel/Insight	Beta	Refrigerant	Quantitative	Field Diagnostics, Inc
Virtjoule	Developing	Power	Timeseries	Virtjoule Inc.
Low Cost SMDS	Developing	Air-Power	Timeseries	Pacific Northwest National Lab

Figure 4 Third Party FDD System Status

Heinemeier describes each system's capability for detecting specific faults as shown below in Figure 5. The list of HVAC faults investigated for this project are mostly included as faults that FDD systems can detect. For example, seven of these nine FDD systems can detect low airflow, six systems can detect low/high refrigerant charge, and eight can detect compressor short cycling. Three faults investigated for this project are not directly included on this list of detected faults. They are refrigerant line restrictions, non-condensables, and high side heat exchange problems. These problems lead to other faults that are included in this list (performance degradation, insufficient capacity); so these faults will be indirectly detected.

O	Basic FDD
X	Extended FDD

	FDSI Insight V.1 Production	Sensus MI	ClimaCheck	SMDS	NILM	Low Cost NILM	Sentinel/Insight Beta Testing	Virtjoule	Low Cost SMDS
Low Airflow	O	O	O		O	O	O	O	
Low/High Charge		O	O		O	O	O	O	
Sensor Malfunction	O	X	O	O			O	X	
Economizer not Functioning	O	X	X	O			O	O	
Compressor Short Cycling	O	X	O		O	O	O	O	O
Excessive Operating Hours	O	X	O				O	O	O
Performance Degradation		O	O	O	O	O	O	O	O
Insufficient Capacity	O	X	O				O	X	O
Incorrect Control Sequence	O	X	O		O	O	O	O	
Lack of Ventilation	O	X		O			O	X	
Unnecessary Outdoor Air	O	X	X	O			O	X	
Control Problems	O	X	O	O			O	O	
Failed Compressor	O	O	O	O	O	O	O	O	
Stuck Damper	O	O	O	O			O	X	
Slipping Belt	O	O	O		O		O	O	
Leaking Valves			O		O		O	X	
Unit Not Operational	O	X		O	O	O	O	O	O

Figure 5 Third Party FDD System Faults Detected

In addition to these third party systems, a number of HVAC OEMs offer fault detection on some of their currently available models. These faults include:

- Air temperature sensor failure/fault
- Low refrigerant charge
- Not economizing when it should/shouldn't
- Damper not modulating
- Excess outside air

Cost-Effectiveness

FDD systems are considered to have a useful life of 15 years. Therefore we calculated estimates for annual energy savings and the resulting value of savings over 15 years, expressed as a present value. Although the savings returned due to FDD systems are realized over a 15 year life, costs are fixed and must be paid at the time of installation and maintenance. By subtracting the costs from the present value of the cumulative savings, we calculated the net financial benefit of the measure.

We conducted the life cycle cost calculation using the California Energy Commission Time Dependent Valuation (TDV) methodology. Each hour is assigned an estimated price for energy,[ii] and the sum of these prices over the life of the measure yields the present dollar value of savings. Life cycle cost is the difference between the TDV $ value for 15 year energy savings and the initial FDD system costs. Cost effectiveness is proved when this difference is positive; in addition, we have reported the benefit/cost ratio as an additional measure of cost effectiveness.

Stakeholder Meetings

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at a number of public Nonresidential HVAC Stakeholder Meetings. At each meeting, the utilities' CASE team invited feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodes.com. Stakeholder meetings were held on the following dates and locations:

- First Nonresidential HVAC Stakeholder Meeting: April 27, 2010, California Lighting Technology Center, Davis, CA.
- FDD Roundtable: July 22, 2010, Western Cooling Efficiency Center, Davis, CA
- Second Nonresidential HVAC Stakeholder Meeting: December 7, 2010, San Ramon Valley Conference Center, San Ramon, CA
- Third Nonresidential HVAC Stakeholder Meeting: March 2011, via webinar.

In addition to the Stakeholder Meetings, a series of other public announcements alerted stakeholders to the proposed changes. These announcements included:

- January 2010: ASHRAE TC 8.11, Orlando, FL
- June 2010: ASHRAE TC 8.11, Albuquerque, NM
- January 2011: ASHRAE TC 8.11, TC 7.5 FDD subcommittee, TC 7.5 main meeting, and 90.1 mechanical subcommittee, Las Vegas, NV

In addition, members of the CASE team travelled to Texas in November 2010 and met with stakeholders at Lennox, Trane, and MicroMetl.

Occupancy Sensor to Setback Thermostat

This proposed measure is to require thermostat temperature setpoint setup/setback when a zone is unoccupied. This applies to multipurpose rooms of less than 1,000 sf, classrooms, and conference rooms served by a single-zone unitary HVAC unit. All of these space types are covered under a mandatory requirement in 2008 Title 24 to control the indoor lighting via occupant sensors, as described in Section 131(d)4:

Offices 250 square feet or smaller; multipurpose rooms of less than 1000 square feet, and classrooms and conference rooms of any size, shall be equipped with occupant sensor(s) to shut off the lighting. In addition, controls shall be provided that allow the lights to be manually shut off in accordance with Section 131(a) regardless of the sensor status.

Occupancy controls for HVAC systems are not currently covered to any extent in Title 24. Thus, the base case is simply not adjusting temperature setpoints or reducing VAV airflow when zones are unoccupied during the occupied schedule.

Depending on the proposed installation, there are three configurations available for a commercial grade thermostat that accepts an occupancy sensor input. Configurations vary based on the location of the occupancy sensor:

- Integrated - Occupancy sensor is integral to the thermostat
- Non-integrated - Occupancy sensor is separate from the thermostat, e.g. ceiling mounted
- Wireless - Combines a door switch and/or window switch with occupancy sensor

The purpose of this project is to determine the feasibility of requiring a thermostat that can accept an input from an occupancy sensor in a space where an occupancy sensor is already required by code to control the lights. Since occupancy sensor will already be in place, there is no need to provide another means to detect occupancy.

Background and Literature Review / Secondary Data Mining

In this task we reviewed the 2008 Title 24 and the ASHRAE 189.1 standards as they both include language related to this measure.

2008 Title 24 Section 122(h) specifies a mandatory requirement for temperature setup/setback:
Automatic Demand Shed Controls*. HVAC systems with DDC to the Zone level shall be programmed to allow centralized demand shed for non-critical zones as follows:*
1. The controls shall have a capability to remotely setup the operating cooling temperature set points by 4 degrees or more in all non-critical zones on signal from a centralized contact or software point within an Energy Management Control System (EMCS).
2. The controls shall remotely setdown the operating heating temperature set points by 4 degrees or more in all non critical zones on signal from a centralized contact or software point within an EMCS.
3. The controls shall have capabilities to remotely reset the temperatures in all non critical zones to original operating levels on signal from a centralized contact or software point within an EMCS.
4. The controls shall be programmed to provide an adjustable rate of change for the temperature setup and reset.

ASHRAE 189.1 specifies a prescriptive option as described here:
7.4.3.12 Automatic Control of HVAC and Lights in Hotel/Motel Guest Rooms. *A minimum of one of the following control technologies shall be required in hotel/motel guest rooms with over 50 guest rooms such that all the power to the lights and switched outlets in a hotel or motel guest room would be turned off when the occupant is not in the room and the space temperature would automatically setback (winter) or set up (summer) by no less than 5ºF (3°C):*
a. Controls that are activated by the room occupant via the primary room access method—key, card, deadbolt, etc.
b. Occupancy sensor controls that are activated by the occupant's presence in the room.

We also reviewed a number of light commercial HVAC demand response programs to determine the typical cooling setup temperature during a demand response event. PG&E's SmartAC program for example increases the cooling setpoint at most 4°F and never for more than six hours per day. This is a typical setup temperature for light commercial HVAC demand response programs.

Data Collection & Surveys

We contacted product distributers to determine the functional differences and costs of various models of commercial thermostats with and without capability for occupancy sensor input. To contact distributors for the survey, we started by using the lists of sales reps on the websites of the following major thermostat manufacturers. Between them, we believe that these manufacturers account for the overwhelming majority of thermostat sales in the state. Manufacturers are listed in alphabetical order:

◆ Aprilaire	◆ Pro1 IAQ
◆ Carrier-Totaline	◆ RCI Automation
◆ Honeywell	◆ RobertShaw
◆ Jenesys	◆ Venstar
◆ LuxPro	◆ Viconics
◆ PECO	◆ White Rodgers

From the websites of these manufacturers we generated a list of sales reps that includes 21 businesses throughout California. All these sales reps were contacted via phone. Of those willing to assist in the survey, we asked each sales rep questions such as:

- Which products (make/model) would you recommend for commercial thermostats that accept an input from an occupancy sensor?
- What are comparable products without an occupancy sensor input?
- What would be the labor time for a certified electrician to complete the installation?
- Can you please provide your thoughts on the relative quality of the thermostats you carry and any additional insights you have about these products?

This survey was intended to be relatively informal and open-ended, and focused on gleaning as much information as possible from the anecdotal responses given by the reps throughout the state. The survey instrument is included in Appendix J: Market Survey for Thermostats.

The scope of this survey was limited to non-integrated thermostats. This is because Title 24 already requires an occupancy sensor as explained earlier. We are interested in determining the incremental cost of this measure, which does not include the existing occupancy sensor.

Because of the lack of published research a two day field study was conducted to estimate the temperature recovery times over a range of various setup/setback temperatures. These field study results were compared with the human comfort specifications as indicated in ASHRAE Standard 55-2010 -- Thermal Environmental Conditions for Human Occupancy.

Energy Savings

A series of energy simulations using the eQUEST energy simulation software was completed to estimate the potential energy savings resulting from use of occupancy sensors to setup and setback the cooling and heating temperature set points during unoccupied daytime (standby) periods in classrooms, conference rooms, and multipurpose rooms. The simulation used a single space, various numbers of exterior surfaces, a range of setup/setback temperatures, and a range of standby period duration as summarized here:

- Climate zones: 3, 6, 9, 12, 14, 16
- Number of exterior walls: 0, 1, 2, 3
- Duration of the standby period: 1, 2, 4, 10 hours
- Temperature setup and setback: 0°F (base case), 2°F, 4°F, 8°F
- System type: packaged single zone constant volume (CAV) with gas furnace & packaged variable air volume (VAV) with a boiler

Four prototype simulation models were developed for the analysis. Figure 6 summarizes a number of key inputs used in the energy simulations:

	Occupancy Type	Area (Square Feet)	Number of Stories	# HVAC Systems	Total tons	Avg sf/ton	Occupancy Schedule
Prototype 1	Conference Rm CAV	375	1	1	1	341	8-6 p.m. M-F
Prototype 2	Classroom CAV	375	1	1	1	341	8-6 p.m. M-F
Prototype 3	Conference Rm VAV	3,750	1	1	1	3,409	8-6 p.m. M-F
Prototype 4	Classroom VAV	3,750	1	1	1	3,409	8-6 p.m. M-F

Figure 6 Summary of Energy Simulation Models for Occupancy Sensors

Measure Cost

The survey described above in Data Collection & Surveys was used to collect cost data on thermostats with and without capability for occupancy sensor input.

Cost-Effectiveness

Thermostats are considered to have a useful life of 15 years. Therefore we calculated estimates for annual energy savings and the resulting value of savings over 15 years, expressed as a present value. Although the savings returned due to thermostats are realized over a 15 year life, costs are fixed and must be paid at the time of installation and maintenance. By subtracting the costs from the present value of the cumulative savings, we calculated the net financial benefit of the measure.

We conducted the life cycle cost calculation using the California Energy Commission Time Dependent Valuation (TDV) methodology. Each hour is assigned an estimated price for energy,[iii] and the sum of these prices over the life of the measure yields the present dollar value of savings. Life cycle cost is the difference between the TDV dollar value for 15 year energy savings and the initial thermostat costs. Cost effectiveness is proved when this difference is positive; in addition, we have reported the benefit/cost ratio as an additional measure of cost effectiveness.

Two-Stage Thermostat

This proposed measure requires a thermostat with two stages of cooling for single zone systems whenever an outside air economizer is present. The base case is a single stage thermostat. There are two ways that economizers can work with a single stage thermostat and both will likely result in reduced energy savings or a disabled system.

1) The single zone thermostat calls for cooling and if the outside air temperature is below the economizer high limit setting, the economizer locks out compressor cooling. If the economizer can't provide full cooling the space gets hotter. This will definitely cause a comfort problem if the high limit is set to the T-24 required values. Typical contractor response is to reset high limit down to 55˚F so the economizer is only enabled when it can provide full cooling. As a result partial economizing is eliminated or in the worst case the economizer cooling may be completely disabled.

2) The single zone thermostat calls for cooling and both compressor cooling and economizer are enabled. Compressor cooling when combined with cold outside air wastes energy if the outside could provide sufficient cooling alone. In addition, the supply air leaving the coil may be cold enough to trigger the low temperature compressor protection which disables the compressor. Excessively low supply air temperature results in wasted dehumidification energy as well as comfort problems. Again these issues may result in the economizer being disabled by contractor.

A two-stage thermostat has two separate cooling setpoints and control terminals, each dedicated to a different stage of cooling control. The first stage enables the economizer and if available and needed it also enables partial compressor cooling. The second stage setpoint enables both the economizer and full compressor cooling. In addition to the two-stage thermostat there must be two separate wires to properly enable the economizer:

First cooling stage. Economizer is enabled. Outside air damper will fully open if outside air temperature is lower than economizer high limit temperature, if outside temperature is too high, the outside air damper remains at minimum ventilation position and if there is a multi-stage compressor, the low output stage is enabled. If the compressor is single stage no compressor cooling is provided during this thermostat stage.

Second cooling stage. If the space gets warmer the thermostat triggers second stage cooling with full compressor cooling. If the outside air temperature is lower than the economizer high limit setpoint, the outside air damper will remain open. If supply air temperature drops below high limit, the damper returns to minimum ventilation.

In summary this measure allows alternating integration of compressor cooling and economizing.

Thermostat Stage	Outside Air Temperature > High Limit	Supply Air Temperature < Low Limit	Outside Air Damper Position	Mechanical Cooling
Stage 1 Setpoint > 72˚F	Yes	NA	Closed (minimum ventilation)	No
	No	NA	Fully Open	
Stage 2 Setpoint > 74˚F	Yes	NA	Closed	Yes

	No	Yes	Closed (alternates open when space temp drops and stage 2 is satisfied)	Yes
		No	Fully Open (alternates closed when stage 2 cooling is enabled)	No

Figure 7 State Table – Two-stage thermostat with single-stage compressor cooling

When there are not enough thermostat wires to connect both cooling terminals, a two-stage thermostat will operate with only one stage of cooling and as described above will greatly reduce the energy savings from the economizer. To upgrade the thermostat wiring for two stages of cooling a new thermostat wire is needed or an electronic device called a multiplexer can be installed to make the single wire carry two separate control signals.

Thermostat Stage	Outside Air Temperature > High Limit	Supply Air Temperature < Low Limit	Outside Air Damper Position	Mechanical Cooling
Stage 1 Setpoint > 72˚F	Yes	NA	Closed (minimum ventilation)	1st Stage
	No	NA	Fully Open	No
Stage 2 Setpoint > 74˚F	Yes	NA	Closed	Full Cooling
	No	Yes	Closed	
		No	Fully Open	

Figure 8 State Table –Two-stage thermostat with multi-stage compressor cooling

In summary, to get the most energy savings benefit from an outside air economizer, the thermostat and its wiring need to provide two separate stages of cooling with the first stage dedicated to economizer only unless there are multiple stages of compressor cooling when it is acceptable for the economizer to work with the first stage of compressor cooling. If there is only one stage of compressor cooling, it must not operate until the second stage of cooling is called for by the thermostat.

Literature Review / Secondary Data Mining

One relevant paper describes five levels of compressor/economizer integration.[iv] It explains that a thermostat with two stages of cooling is needed (one stage dedicated to the economizer) to achieve the best possible integration with a single-stage direct-expansion cooling unit. This is known as alternating integration. The first cooling stage activates the economizer. When the second stage is activated, the cooling compressor operates and the economizer dampers reduce the outside air to avoid comfort problems from discharge air that is too cold. With a single-stage cooling thermostat, the control sequence is time delay integration. On a call for cooling, the economizer operates for a set period of time (typically 5 minutes). If there is still need for cooling, the cooling coil operates.

Data Collection & Surveys

In conjunction with the occupancy sensor measure, we contacted product distributers to determine the functional differences and costs of various models of single-stage and two-stage commercial thermostats. Of those willing to assist in the survey, we asked each sales rep questions such as:

- Which products (make/model) would you recommend for commercial thermostats with a single cooling stage? What is the cost for these models?
- What are comparable products with two cooling stages? What is the cost for these models?
- What would be the labor time for a certified electrician to complete the installation?
- Can you please provide your thoughts on the relative quality of the thermostats you carry and any additional insights you have about these products?

This survey was intended to be relatively informal and open-ended, and focused on gleaning as much information as possible from the anecdotal responses given by the reps throughout the state. The survey instrument is included in Appendix J: Market Survey for Thermostats.

Energy Savings

A series of energy simulations using the eQUEST energy simulation software was completed to estimate the potential energy savings resulting from use of a two-stage thermostat. The current simulation of economizers in DOE 2.2 with the Packaged Single Zone (PSZ) system has a known problem in that as an hourly simulation it cannot simulate switching between a single stage DX coil cooling operation (that needs to reduce the outside air to avoid comfort problems and coil freezing) and economizer operation where supply air temperature is not an issue. The present routine exaggerates the savings that will accrue from an economizer in a single-stage cooling unit. The energy savings methodology relies on a work around to correct the simulation as described in Appendix K: Modeling Guidance for RTU Economizers.

The simulation used a three story building based on the medium office from the DOE set of reference building models. This model has 5 zones plus plenum per floor, a range of window to wall ratio, and a range of occupancy type as summarized here. The results are presented in the Energy simulation section.

- Climate zones: 3, 6, 9, 12, 14, 16
- Window to wall ratio: 10%, 30%, 60%
- Occupancy type: high density office, low density office, retail, primary school
- Economizer operation: one-stage thermostat (base case), two-stage thermostat

Measure Cost

The survey described above in the Data Collection & Surveys section was used to collect cost data on single-stage and two-stage thermostats.

Cost-Effectiveness

Thermostats are considered to have a useful life of 15 years. Therefore we calculated estimates for annual energy savings and the resulting value of savings over 15 years, expressed as a present value. Although the savings returned due to thermostats are realized over a 15 year life, costs are fixed and must be paid at the time of installation and maintenance. By subtracting the costs from the present value of the cumulative savings, we calculated the net financial benefit of the measure.

We conducted the life cycle cost calculation using the California Energy Commission Time Dependent Valuation (TDV) methodology. Each hour is assigned an estimated price for energy,[v] and the sum of these prices over the life of the measure yields the present dollar value of savings. Life cycle cost is the difference between the TDV dollar value for 15 year energy savings and the initial thermostat costs. Cost effectiveness is proved when this difference is positive; in addition, we have reported the benefit/cost ratio as an additional measure of cost effectiveness.

Economizer Size Threshold

The purpose of this measure is to revise the minimum size requirement for economizers by lowering the threshold to cover all sizes of unitary equipment where the economizer is determined to be cost-effective.

Literature Review / Secondary Data Mining

Currently, economizers are required on air conditioners with capacities greater than or equal to 75,000 Btu/hr (6.25 tons) per 2008 Title 24. ASHRAE 189, ASHRAE 90.1-2010, and IECC-2012 all have lower thresholds as shown below in Figure 9.

2008 Title 24	≥ 75,000 Btu/h
ASHRAE 90.1-2010	≥ 54,000 Btu/h
ASHRAE 189.1, IECC-2012	≥ 33,000 Btu/h

Figure 9 Summary of Economizer Size Requirements by Energy Code

A significant body of work on this topic is the analysis conducted in support of the ASHRAE 90.1-2010 economizer addendum. Dick Lord of Carrier led this analysis and presented the results at the January 2010 ASHRAE meeting in Orlando. The analysis relied on the 90.1 benchmark building models for small office, large office, and hospital. They ran the models for all 17 ASHRAE climate zones and looked at changeover control options including fixed drybulb without integration, fixed drybulb with integration, differential drybulb, fixed enthalpy, differential enthalpy and electronic enthalpy. They based the design life on 15 years and considered fuel escalation rate, state and federal tax rates, discount rate and interest rate to yield a scalar of 8.8 years. Scalar refers to the simple payback in years, in this case 8.8 years simple payback. The results are reported in the section Economizer Size Threshold.

Cost Data Collection

We contacted product distributers representing the following companies to determine the incremental cost of economizers over a range of equipment capacities from 3 tons to 60 tons:

- Aaon
- Carrier
- Trane
- York

Energy Savings

Using California energy costs, the analysis methodology for the ASHRAE 90.1-2010 economizer addendum indicates economizers are cost effective down to at least 24,000 Btu/h. To estimate the energy savings of the proposed changes using the CEC Life Cycle Cost Analysis (LCCA) methodology, we developed a series of DOE-2 prototype models. These are the same base models used for the two-stage thermostat analysis as previously described. The only difference in the base models is that for this measure the economizer operation base case is no economizer and the measure case is a temperature-based economizer.

Measure Cost

The survey described above in Cost Data Collection was used to collect cost data on economizers. The results are presented in the section Measure Cost.

Cost-Effectiveness

Some energy efficiency measures have continuous levels. Insulation is an example, as is this economizer measure. The approach used for determining the life-cycle cost choice for continuous measures is to search for the level of the measure that reduces life-cycle cost the most, relative to the base case. This is comparable to ranking the measures by energy saving potential and showing that each incremental change is cost effective relative to the previous measure.[vi] Thus, this measure will be economically feasible as we determine the threshold of cost effectiveness and propose adjusting the current standard accordingly.

Economizers are considered to have a useful life of 15 years. Therefore we calculated estimates for annual energy savings and the resulting value of savings over 15 years, expressed as a present value. Although the savings returned due to economizers are realized over a 15 year life, costs are fixed and must be paid at the time of installation and maintenance. By subtracting the costs from the present value of the cumulative savings, we calculated the net financial benefit of the measure.

We conducted the life cycle cost calculation using the California Energy Commission Time Dependent Valuation (TDV) methodology. Each hour is assigned an estimated price for energy,[vii] and the sum of these prices over the life of the measure yields the present dollar value of savings. Life cycle cost is the difference between the TDV dollar value for 15-year energy savings and the initial economizer costs. Cost effectiveness is proved when this difference is positive; in addition, we have reported the benefit/cost ratio as an additional measure of cost effectiveness.

Economizer Damper Leakage

This proposal will set the maximum damper leakage at 10 cfm/sf statewide.

Mapping the California climate zones to the ASHRAE climate zones shows only two regions in California with a requirement other than 10 cfm/sf. ASHRAE climate zones 2B (El Centro) and 6B (Eastern Sierra south of Lake Tahoe) require 4 cfm/sf. This proposal for 10 cfm/sf statewide is backpedaling from 90.1-2010, but these two small, sparsely-populated regions are not worth the potential confusion; it is better to maintain a single common statewide standard. The analysis and results are presented in the section Economizer Damper Leakage.

There is stakeholder support for this proposal, including support from AHRI. They developed a series of comments in response to PECI's memorandum on the proposed requirements. PECI issued this memorandum on June 22, 2010 to ASHRAE's Technical Committee 8.11. Through written comments provided in November 2010, AHRI stated: "Our recommendation is that the Title 24 should use the same requirements that are in the 2010 ASHRAE 90.1 standard."

Economizer Reliability

This is a two-part proposal. The first part would require certain performance features to improve the economizer reliability. These features are:

- 5-year performance warranty of economizer assembly
- Direct drive modulating actuator with gear driven interconnections
- If the high-limit control is fixed dry-bulb, it shall have an adjustable setpoint
- Primary damper control temperature sensor located after the cooling coil to maintain comfort
- Provide an economizer specification sheet proving capability of operating after at least 100,000 actuator open and closed cycles
- System is designed to provide up to 100% outside air without over-pressurizing the building
- Sensors used for the high limit control are calibrated with the following accuracies. This includes the outdoor air temperature or enthalpy sensor. This also includes the return air temperature or enthalpy sensor in the case of differential control.
    - Temperatures accurate to ± 1°F
    - Enthalpy accurate to within ± 1 Btu/lb
    - Relative humidity accurate to within 5%
- Sensor performance curve is provided with economizer instruction material. In addition, the sensor output value measured during sensor calibration is plotted on the performance curve.
- Sensors used for the high limit control are located to prevent false readings, e.g. properly shielded from direct sunlight.
- Designed and tested in accordance with AMCA Standard 500 for a maximum leakage rate of 10 cfm/sf at 1.0 in. w.g.

The second part of this proposal includes revising the current option for RTU manufacturers to apply to the CEC for certification for a factory installed and calibrated economizer. The motivation for these changes is to encourage more factory installation instead of field installation of economizers.

As described later in this section, factory installed economizers prove more reliable in part due to quality control and check out procedures available in the production environment.

For certified equipment, the economizer is exempted from the functional testing requirements (but not the construction inspection requirements) as described in Standards Appendix NA7.5.4 “Air Economizer Controls” and on the MECH-5 acceptance testing form. The proposed changes would require acceptance testing that is expanded and more rigorous if the economizer is not factory installed and certified. For example, the following additional construction inspection tasks are required for economizers that are not factory installed and certified. This is in addition to all the functional testing requirements that are required for a field installed economizer.

- Verify the economizer lockout control sensor is located to prevent false readings, e.g. shielded from direct sunlight;
- Verify the system is designed to provide up to 100% outside air without over-pressurizing the building;
- For systems with DDC controls, lockout sensor(s) are either factory calibrated or field calibrated;
- Provide a product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf at 1.0 in w.g.;
- Sensors used for the high limit control are calibrated at factory or in field;
- Sensor output value measured during sensor calibration is plotted on the performance curve.

The methodology used to develop this proposal primarily relied on secondary data mining (for example using PECI’s AirCare Plus program database) and conducting lab testing.

Background and Literature Review / Secondary Data Mining

In this task we conducted a literature review to investigate the current state of the market in terms of economizer reliability. An annotated bibliography summarizing this literature review is included at the end of this report in the section Bibliography and Other Research.

For the data mining task we relied on PECI’s AirCare Plus (ACP) program, which provides failure data for economizers. ACP is a comprehensive diagnosis and tune-up program for light commercial unitary HVAC equipment between 3 and 60 tons cooling capacity. This program has been active throughout the PG&E service territory since 2006 and throughout the Southern California Edison service territory since 2004. It includes inspection of the following HVAC components: thermostat controls, economizers, refrigerant charge, and airflow. The ACP program database includes over 17,000 RTUs with documented status of these HVAC components. This massive collection of HVAC data proved useful in identifying the failure data for economizers.

Data Collection & Surveys

An earlier idea for this CASE study that was later dropped on account of preemption concerns was manufacturers shall attain certification for RTUs sold in California and 1 of every 1000 units sold in California shall be tested. The feasibility of third-party testing was evaluated by executing example tests at an HVAC test facility. Lab testing was conducted at Intertek’s HVAC test facility in Dallas, Texas in late October 2010, as this facility has a number of psychrometric chambers configured to provide specific indoor and outdoor test conditions. Appendix F: Economizer Reliability Lab Testing explains the results of this work.

Energy Savings

The energy savings analysis is based on the Advanced Rooftop Unit (ARTU) PIER project.[viii]

Measure Cost

This measure will allow an option for reduced cost for compliance. RTU manufacturers can apply to the CEC for a certification for a factory installed and calibrated economizer. This is a one time process for each RTU model. For certified equipment, the economizer is exempted from the functional testing requirements in the Air Economizer Controls acceptance test. The measure cost analysis for the performance features is derived from the ARTU project cost benefit analysis.

Cost-Effectiveness

Economizers are considered to have a useful life of 15 years. Therefore we calculated estimates for annual energy savings and the resulting value of savings over 15 years, expressed as a present value. Although the savings returned due to economizers are realized over a 15 year life, costs are fixed and must be paid at the time of installation and maintenance. By subtracting the costs from the present value of the cumulative savings, we calculated the net financial benefit of the measure.

High Limit Switch Performance

To test the impact on energy usage of the various high limit control options including sensor error, a DOE-2.2 model was created of a typical office building. DOE-2.2 was used (as opposed to other simulation engines like EnergyPlus) because it is capable of modeling high limit sensor error. The building modeled is one story, 40,000 ft^2 gross area, and served by a variable air volume system and an all-variable speed chilled water plant. The roof insulation was modeled as R-50 to minimize the effect of the roof properties in order to represent a mix of single story buildings, and intermediate floors within high-rise buildings (where there would be no roof effects). All other building envelope properties were adjusted to meet Title 24 requirements in Climate Zone 6, which was deemed an intermediate and representative climate.

Sensor error was assumed to be ±2°F for drybulb sensors and ±4%RH for humidity sensors. These assumptions are deliberately skewed toward penalizing the drybulb sensors and ignoring the significant evidence of poor performing humidity sensors to make our conclusions below even more credible. Error was modeled as cumulative for multiple sensors (both low or both high), rather than using a statistical (e.g. root mean square[ix]) approach to bound the possible error.

Seven high limit controls and combinations were modeled, summarized in Table 2 below. These strategies cover the most common high limit strategies and the options that are allowed prescriptively within Title 24, with the exception of the electronic enthalpy strategy, which cannot be modeled explicitly within eQUEST. The fixed enthalpy + fixed drybulb strategy is a newly identified control option that is not yet standard practice. Assumed combined sensor accuracy is listed. A ±2°F drybulb error equates to about ±1.2 Btu/lb$_{da}$ enthalpy error while a ±4%RH error equates to a ±0.8 Btu/lb$_{da}$ enthalpy error for a total of 2 Btu/lb$_{da}$ enthalpy error. This same enthalpy error can result with a perfect drybulb sensor and a ±10%RH humidity sensor error.

	High Limit Control Option	Setpoint	Error	Remarks

	High Limit Control Option	Setpoint	Error	Remarks
1	Fixed Drybulb	See Remarks	±2°F	The fixed drybulb setpoint was that which resulted in the lowest energy usage for each climate zone.
2	Dual Drybulb	–	±4°F	Twice the error due to two sensors
3	Fixed Enthalpy	28 Btu/lb_{da}	2 Btu/lb_{da}	Cumulative error of ±2°F drybulb and ±4%RH
4	Dual Enthalpy	–	4 Btu/lb_{da}	Twice the error due to two sensors
5	Dual Enthalpy + Fixed Drybulb	– 75°F	4 Btu/lb_{da} ±2°F	Separate error impact modeled for both sensors. Dual drybulb was not modeled because DOE-2.2 does not allow it to be combined with Dual enthalpy.
6	Dewpoint + Fixed Drybulb	55°F 75°F	5°F DPT ±2°F	This option was analyzed only because it is listed as an option in Standard 90.1.
7	Fixed Enthalpy + Fixed Drybulb	28 Btu/lb_{da} 75°F	2 Btu/lb_{da} ±2°F	Separate error impact modeled for both sensors

Table 2 – High Limit Control Modeling Summary

Analysis and Results

Fault Detection and Diagnostics (FDD)

FDD is included in 2008 Title 24 as a compliance option. This proposal is to advance FDD as a prescriptive option.

Results of FDD Research

Numerous HVAC faults were investigated in this study to determine the potential benefit of FDD systems in detecting these faults, including:

1. Air temperature sensor failure/fault
2. Low refrigerant charge
3. High refrigerant charge
4. Compressor short cycling
5. Refrigerant line restrictions/TXV problems
6. Refrigerant line non-condensables
7. Low side HX problem
8. High side HX problem
9. Capacity degradation
10. Efficiency degradation
11. Not economizing when it should
12. Damper not modulating
13. Excess outdoor air

A number of the HVAC faults listed above cannot be directly modeled using the energy simulation tool EnergyPro. In such incidences the failure mode is described by a corresponding EER penalty, which is then modeled in EnergyPro as a lower EER. The values of the EER penalties are from "Evaluation Measurement and Verification of Air Conditioner Quality Maintenance Measures, Mowris, October 2010," which are based on lab testing conducted by Robert Mowris Associates at the Intertek testing facility in Dallas, Texas in October 2010. Descriptions of the investigated failure modes and the modeling assumptions used are included below.

1. **Air temperature sensor failure/fault** - This failure mode is a malfunctioning air temperature sensor, such as the outside air, discharge air, or return air temperature sensor. This could include mis-calibration, complete failure either through damage to the sensor or its wiring, or failure due to disconnected wiring. Calibration issues are more common than sensor failures, thus we modeled this fault as a calibration problem. Temperature sensors are commonly accurate to ± 0.35°F. For a conservative estimate we modeled this fault as ± 3°F accuracy. Calibration errors greater than this and failed sensors will contribute to an even worse energy impact.

2. **Low refrigerant charge: 80% of nominal charge** - Incorrect level of refrigerant charge is represented in this failure mode, designated by a 20% undercharge condition (80% of nominal charge). Refrigerant undercharge may result from improper charging or from a refrigerant leak. While the most common concern about a refrigerant leak is that a greenhouse gas has been released to the atmosphere, a greater impact is caused by the additional CO_2 emissions from fossil fuel power plants due to the lowered efficiency of the HVAC unit.

A typical symptom is low cooling capacity as the evaporator is starved of refrigerant and cannot absorb its rated amount of heat. This causes a high evaporator superheat as the receiver is not getting enough liquid refrigerant from the condenser, which starves the liquid line. The thermal expansion valve (TXV) experiences abnormal pressures and cannot be expected to control evaporator superheat under these conditions. The compressor is pumping only a small amount of refrigerant. Essentially, all the components in the system will be starved of refrigerant.

EnergyPro does not allow a specific model input related to refrigerant charge. Instead, the simulation used -15% EER (a 15% reduction in the rated EER), equivalent to 80% charge, based on laboratory testing results,[x] as shown in Figure 10.

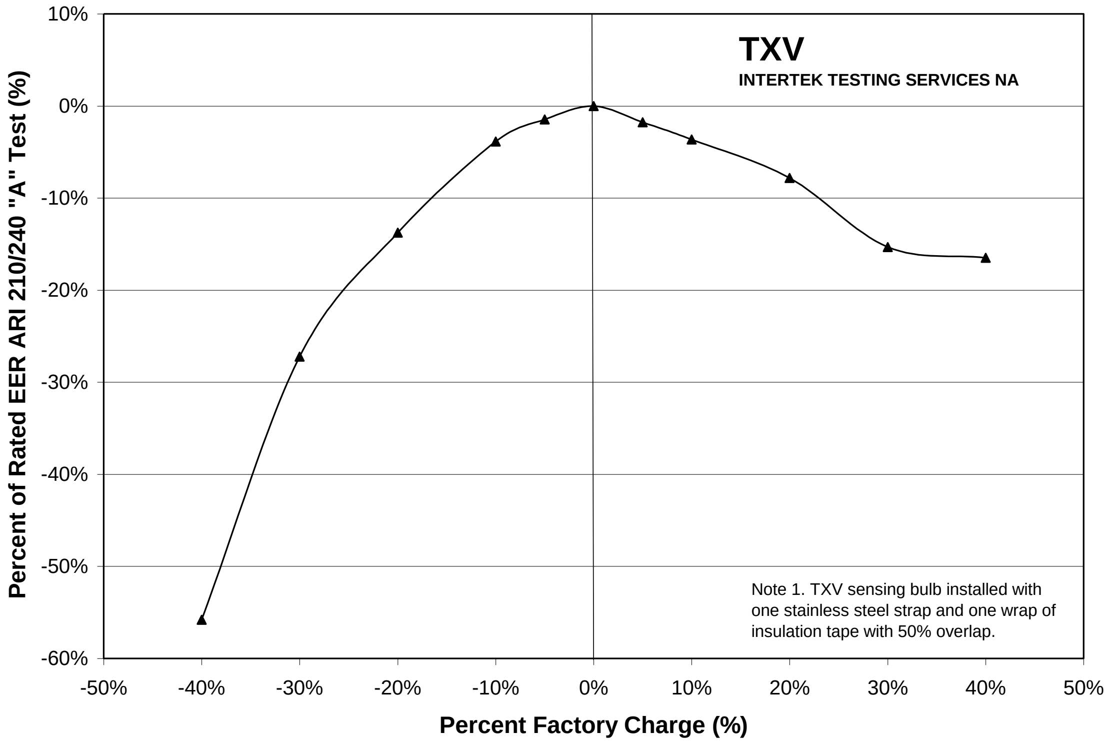


Figure 10 Impact of Refrigerant Charge on EER

3. **High refrigerant charge: 120% of nominal charge** - Incorrect level of refrigerant charge is represented in this failure mode, designated by a 20% overcharge condition (120% of nominal charge). This fault was added to the list after conducting the energy analysis and therefore is not included in the energy analysis. The energy analysis is thus conservative as it does not include this fault.

4. **Compressor short cycling** - Compressor short cycling means that the compressor is enabled again shortly after being stopped for only a brief period of time. Some manufacturers recommend a minimum runtime of 3 minutes and minimum off time of 2 minutes. Thus, short cycling could be considered a runtime shorter than 3 minutes and off time shorter than 2 minutes. Short cycling can originate from many sources, for example coil blockage, equipment oversizing, and a poor thermostat location (e.g. near a supply air diffuser).

It takes about three minutes of runtime for an RTU to achieve steady state operation and full cooling output. During this time, the unit efficiency is reduced as the refrigerant pressures are established and the evaporator coil cools down. When a unit is short cycling, the startup time becomes a higher fraction of the total runtime. The startup losses thus become a higher fraction of the total cooling output such that the overall efficiency is reduced.

A runtime of 3 minutes and off time of 2 minutes corresponds to a runtime fraction of 60%[xi] and an efficiency penalty of 10% according to AEC's Small HVAC System Design Guide.[xii] EnergyPro does not allow a specific model input related to compressor short cycling. Instead, the simulation used -10% EER, equivalent to 60% runtime fraction.

Short cycling affects maintenance and repair costs in addition to operating costs. It is one of the most common causes of RTU early maintenance problems and compressor failures. Each time the compressor starts, there is a quick reduction in the crankcase pressure, which results in a portion of the crankcase oil getting pumped out of the compressor. The oil will eventually return to the compressor given sufficient runtime, otherwise the oil will be trapped in the system when the compressor cycles off. With short cycling, the compressor will continue to pump oil from the crankcase, and the entire oil charge can be lost from the crankcase. Without proper lubrication to the compressor, premature failure can result. Compressor short cycling can also cause liquid refrigerant flooding, again threatening premature failure. The compressor starts against nearly full high side discharge pressure, which leads to very high loading of the mechanical components. The electrical components can also be affected, as they are subjected to an unusually high starting current, creating excessive heat and leading to compressor motor overheating.

5. **Refrigerant line restrictions/TXV problems** - Refrigerant line restriction means the refrigerant flowrate is constrained due to a blockage in the refrigerant line. A restriction always causes a pressure drop at the location of the restriction. A suction line restriction will cause low suction pressure and starve the compressor and condenser. This can be caused by restricted and/or dirty suction filters or a bent or crimped refrigerant line from physical damage. A liquid line restriction will cause low pressure and a temperature drop in the liquid line and starve the evaporator, compressor, and condenser. This can be caused by a bent or crimped refrigerant line, a restricted and/or dirty expansion device such as a TXV, a restricted liquid line filter/dryer, or a pipe joint partially filled with solder. In the case of a bent refrigerant line, it acts like an expansion device such that two expansion devices effectively operate in series causing a higher than normal pressure drop. The low evaporator temperature can freeze the evaporator coil and suction line.

EnergyPro does not allow a specific model input related to this fault. Instead, the simulation used -56% EER. This comes from lab test work funded through the Texas A&M Energy Systems Laboratory, which reports that reduced mass flow rate caused by a liquid line restriction reduces the EER by 56%.[xiii] Based on the same lab testing, reduction in suction line decreased the EER by 27%. We choose to model the EER penalty as 56% since there is a much higher probability of damage to the liquid line as the suction line pipes are relatively sturdy.

6. **Refrigerant line non-condensables** - Refrigerant line non-condensables means a type of contaminant has entered the refrigeration lines. This is commonly air, water vapor, or nitrogen. They enter the system through leaks or poor service practices, such as not purging refrigeration hoses while working on a unit or not completely evacuating the system after it has been open for repair. The only fluids in a refrigeration system should be refrigerant and oil. Any other fluids contained within the system can reduce its cooling capacity and lead to premature failure. When air enters a

system it will become trapped in the condenser and will not condense. This results in less surface area available for the refrigerant to condense, thus decreasing the capacity of the condenser and increasing its pressure. This causes the compressor to work harder, degrading its efficiency and potentially damaging it by overheating.

EnergyPro does not allow a specific model input related to refrigerant line non-condensables. Instead, the simulation used -8% EER as shown below in Figure 11, which comes from lab testing conducted by Mowris.[xiv]

Description	Air-Side EER Impact	Total Air-Side Cooling Capacity Btu/hr	Air-Side EER	Total Air Conditioner Power kW	Impact on Air Conditioner Power kW
Baseline total charge 6 lb. 12.2 oz. (228 psig liquid pressure)	NA	31,976	9.69	3.297	NA
Non-Condensable evacuate charge, sweep with Nitrogen, vent to atmospheric pressure (0.3 oz. nitrogen) total charge 6 lb. 12.2 oz. (267 psig liquid pressure)	-7.94%	32,625	9.04	3.608	9.6%

Figure 11 Impact of Non-Condensables on EER

7. **Low side (evaporator) heat exchange problem -** This failure mode is low airflow through the evaporator coil as measured at the unit's supply air discharge. This could be caused by an evaporator coil blockage for example. When the evaporator coil has a reduced airflow, there is reduced heat load on the coil. This can cause the refrigerant in the coil to remain a liquid and not vaporize. The liquid refrigerant will travel past the evaporator coil and reach the compressor, thus flooding and damaging it.

ARI standards are based on airflow rates of 400 cfm/ton. AEC's Small HVAC System Design Guide reports that 39% of units have airflow less than or equal to 300 cfm/ton.[xv] Figure 12 shows the corresponding distribution of measured airflow reported by this study.

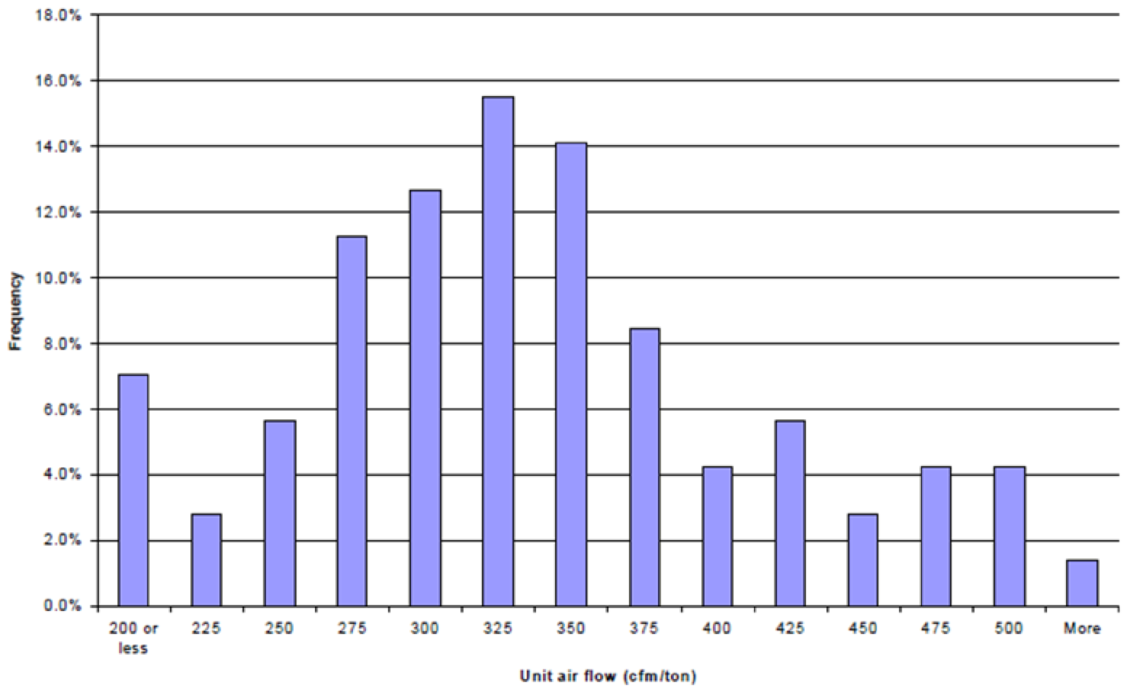


Figure 12 Airflow Distribution in Small Commercial HVAC Units

EnergyPro does not allow a specific model input related to low airflow. Instead, the simulation used -5% EER, equivalent to a low airflow of 300 cfm/ton, from the Mowris study[xvi], as shown below in Figure 13.

Airflow cfm/ton	EER	EER Impact	Airflow % of Baseline
390.5	9.49	NA	NA
351.0	9.19	-3.16%	-12%
301.5	9.04	-4.74%	-25%
249.6	8.39	-11.59%	-37.5

Figure 13 Impact of Low Airflow on EER

8. **High side (condenser) heat exchange problem** - This failure mode is a 50% condenser coil blockage. In this case, the condenser fails to properly condense the refrigerant vapor to a liquid in the middle of the condenser. EnergyPro does not allow a specific model input related to condenser coil blockage. Instead, the simulation used -9% EER, equivalent to 50% condenser coil blockage, from the Mowris study as shown in Figure 14.[xvii]

Description	Air-Side EER Impact	Total Air-Side Cooling Capacity Btu/hr	Air-Side EER	Total Air Conditioner Power kW	Impact on Air Conditioner Power kW
Baseline	NA	32,335	9.82	3.292	NA
30% Condenser Coil Block	-3.69%	32,136	9.46	3.397	3.19%
50% Condenser Coil Block	-9.07%	31,439	8.93	3.52	6.93%
80% Condenser Coil Block	-32.08%	27,806	6.67	4.168	26.61%

Figure 14 Impact of Condenser Coil Blockage on EER

9. **Capacity degradation** - This fault was added to the list after conducting the energy analysis and therefore is not included in the energy analysis. The energy analysis is thus conservative as it does not include this fault.

10. **Efficiency degradation** - This fault was added to the list after conducting the energy analysis and therefore is not included in the energy analysis. The energy analysis is thus conservative as it does not include this fault.

11. **Not economizing when it should** – This was represented as economizer high limit setpoint is 55˚F instead of 75˚F. An economizer is equipped with a changeover (high limit) control that returns the outside air damper to a minimum ventilation position when the outside air is too warm to provide cooling. Economizers should use a 75˚F high limit setpoint in climate zones 1, 2, 3, 5, 11, 13, 14, 15 and 16, per Title 24 Table 144-C as referenced in Section 144(e)3. This failure mode is easily modeled by changing the high limit setpoint from 75˚F (base case) to the failure mode of 55˚F. The 55˚F setting instead of the 75˚F setting results in missed opportunities for free cooling between the range of 55˚F and 75˚F, thus losing a large number of economizer hours and energy savings potential.

The baseline economizer control is a snap disk, which is a round silver temperature sensor that typically has a setpoint of around 55°F; an adjustable setting might be up to 60°F, but not higher with a single stage thermostat. This type of sensor severely limits economizer operation.

Many economizer controllers have the high limit or change over control listed as A B C D rather than a particular temperature. The high limit settings for these labels are shown in Figure 15. The proper temperature high limit to use is the cut-out position of the high limit (or upper end of the control hysteresis) based on the controller and sensor combination. Note that the screw dial can be set between letters.

High Limit Setting	Controller with dry-bulb sensor	Economizer Controller with dip switch settings (switch 1-Switch 2)
D	55°F	55°F (OFF-ON)
D-C	62°F	60°F (OFF-OFF factory)
C	68°F	65°F (ON-OFF)
C-B (desired setting)	75°F	single sensor high limit cannot be set above 65°F high limit
B	82°F	
A	95°F	

Figure 15 Economizer High Limit Settings for Two Controllers

12. **Damper not modulating** – This was represented as economizer stuck closed. When the economizer damper is stuck closed the unit fails to provide any ventilation and is a missed

opportunity for free cooling, thus causing an energy penalty during periods when free cooling is available. This was modeled as “no economizer” in EnergyPro.

13. **Excess outdoor air** – This was represented as economizer stuck 100% open. When the economizer damper is stuck open the unit provides an excessive level of ventilation, usually much higher than is needed for design minimum ventilation. It causes an energy penalty during periods when the economizer should not be enabled, that is, during heating and when outdoor conditions are higher than the economizer high limit setpoint. During heating mode the stuck open economizer will bring in very cold air and the gas usage will increase significantly. This was modeled as 100% outside air in EnergyPro.

Energy simulation

This analysis used a special version of EnergyPro 5.1 that has been configured to use the 2013 weather files developed for the 16 different climate zones by Joe Huang with Whitebox Technologies for the CEC. These climate zone files are intended to serve as the reference data for 2013 code analysis. The version of EnergyPro was configured identically to the version certified for use with the 2008 Title 24 standards, outside of the weather file change.

A series of prototype buildings were developed that were based upon actual project designs in terms of building configuration. Thus for the large retail example, an actual big box retail store was used so that we would have a realistic approximation of glazing area, number of stories and building geometry. In the case of each prototype, each building was configured with Title 24 standard assumptions for insulation levels and glazing type and a standard lighting power density was used. Since the Alternative Calculation Method (ACM) manual rules are applied automatically by EnergyPro during the analysis, assumptions like occupant densities, ventilation rates, etc are all automatically set to the standard values listed in the ACM manual. The HVAC systems in each case were configured as standard Packaged Rooftop Gas Heat/Electric Air Conditioning systems with minimum efficiencies as specified in either Title 24 or Title 20, depending upon system size. Since part of the study includes looking at the effectiveness of economizers, each system was configured with an economizer, even though the requirements in section 144 of the code may not require it be installed.

Once each prototype was developed, a series of runs was performed in the 16 different climate zones. Each run looked at the implications of the degradation of certain portions of the HVAC system. Features such as an economizer that is stuck open, systems that have short cycling, incorrect thermostat signals, etc were analyzed and compared to the basecase that assumes a perfectly functioning system.

For efficiency, simulations are needed only at three EER values to define a curve. The resulting energy savings and TDV savings are directly proportional to the EER penalty. Thus, any additional failure modes described by an EER penalty can be derived from these three models via interpolation. Any failure modes not described by an EER penalty will of course still require a unique simulation. This is summarized below in Figure 16. An example interpolation is shown in Figure 17 and Figure 18 for a 5-ton RTU, small office, in climate zone 12.

Failure mode	EER penalty	Energy savings calculation method
Low airflow: 300 cfm/ton	5%	Simulation
Low side HX problem incl. low airflow (50% evaporator coil blockage)	5%	Simulation
Refrigerant charge: 80% of nominal charge	15%	Simulation
Performance degradation: 30% cond. block, 300 cfm/ton, -10% charge	21%	Simulation
Refrigerant line non-condensables	8%	Interpolation
High side HX problem (50% condenser coil blockage)	9%	Interpolation
Compressor short cycling	10%	Interpolation
Refrigerant line restrictions/TXV problems	56%	Extrapolation

Figure 16 FDD Failure Modes by EER Penalty

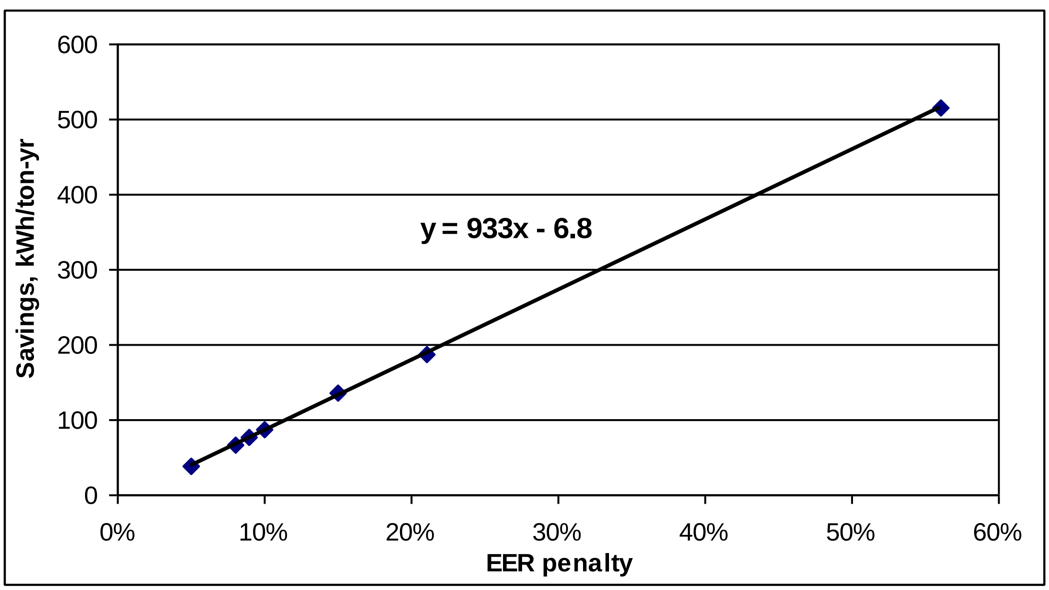


Figure 17 Electric Savings as Function of EER Penalty, 5-ton RTU, Small Office, CTZ 12

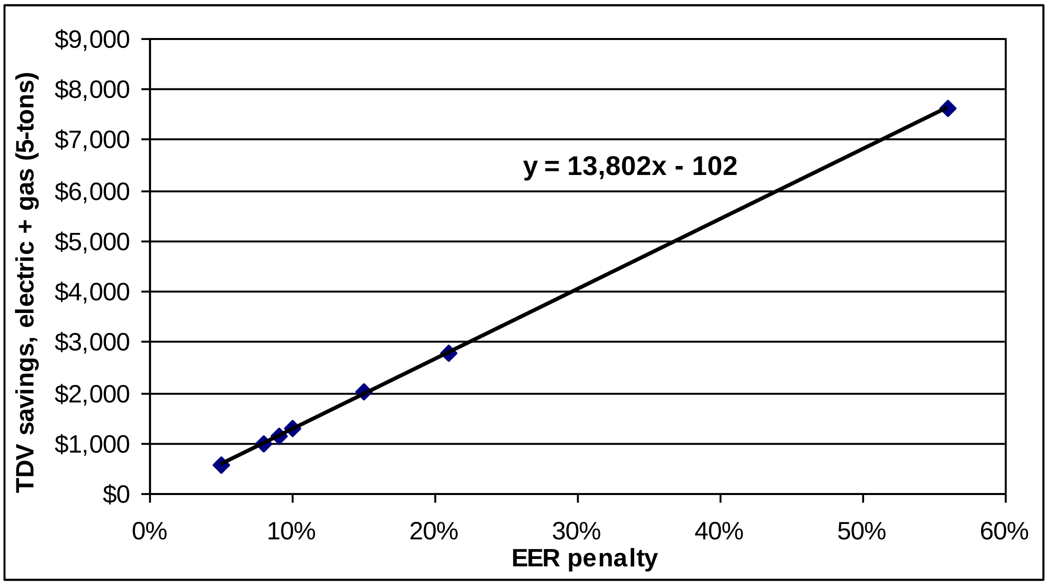


Figure 18 TDV Energy Savings as Function of EER Penalty, 5-ton RTU, Small Office, CTZ 12

Probability Analysis

Thus far, the energy savings described above assumes a 100% failure rate, a 100% chance of the FDD system detecting the fault, and a 0% chance the fault would be detected without an FDD system. In reality, not all units will experience all these faults, the chance of the FDD system detecting the fault is less than 100%, and the chance the fault would be detected without an FDD system is greater than 0%. It is necessary to account for this to avoid overestimating the potential energy savings from implementing an FDD system. This section describes the methodology used to estimate the failure rate and the probability of detecting the faults with and without an FDD system. This method does not account for any interactive effects if multiple failures are encountered, but provides a reasonable distribution of outcome for each test.

This analysis relies on fault incidence. Incidence is the frequency at which a fault occurs in a specific time period or the rate of occurrence of new cases of a fault in the population of interest (e.g., all RTUs in California).

$$Incidence = \frac{\text{Number of units in a population developing the fault in a time interval (e.g., a year)}}{\text{Total number of units in the population during the time interval of measurement}}$$

This is not to be confused with prevalence, which is the number of cases that exist in the population of interest at a specific point in time. For example, the number of economizer faults in all packaged units in the U.S. presently.

$$Prevalence = \frac{\text{Number of units in the population with the fault at a specific time}}{\text{Total number of units in the population at a specific time}}$$

For example, with regard to the refrigerant line restriction fault, it is reported as a 60% probability that a filter/dryer restriction fault will occur once during the equipment lifetime.[xviii] Adding the probability of damage to the liquid line and other restrictions yields an estimated 75% probability for a refrigerant line restriction/TXV fault during the equipment lifetime. Considering the average air conditioner lifespan of 18.4 years as reported by the DOE[xix], the annual incidence is 75% ÷ 18.4 = 4.1%. This means 4.1% of RTUs will develop a refrigerant line restriction fault each year. Considering the 15 year nonresidential analysis period, 62% (4.1% x 15) of RTUs will develop a refrigerant line restriction fault within 15 years.

Figure 19 and Figure 20 show the number of faults identified by the AirCare Plus (ACP) program as a function of the unit's vintage. The slope of the linear trendlines indicate the number of new faults per year. This is presented for the first five years of a unit's lifetime. In other words, this dataset contains the newest units in the entire ACP dataset. This allows for new equipment design and factory assembly and quality control processes that may affect the incidence of faults, while avoiding most obsolete designs and processes. To convert this data to incidence, these number of new faults per year are simply divided by the total number of units in the population during the time interval of measurement (units tested/yr). Figure 21 summarizes the results.

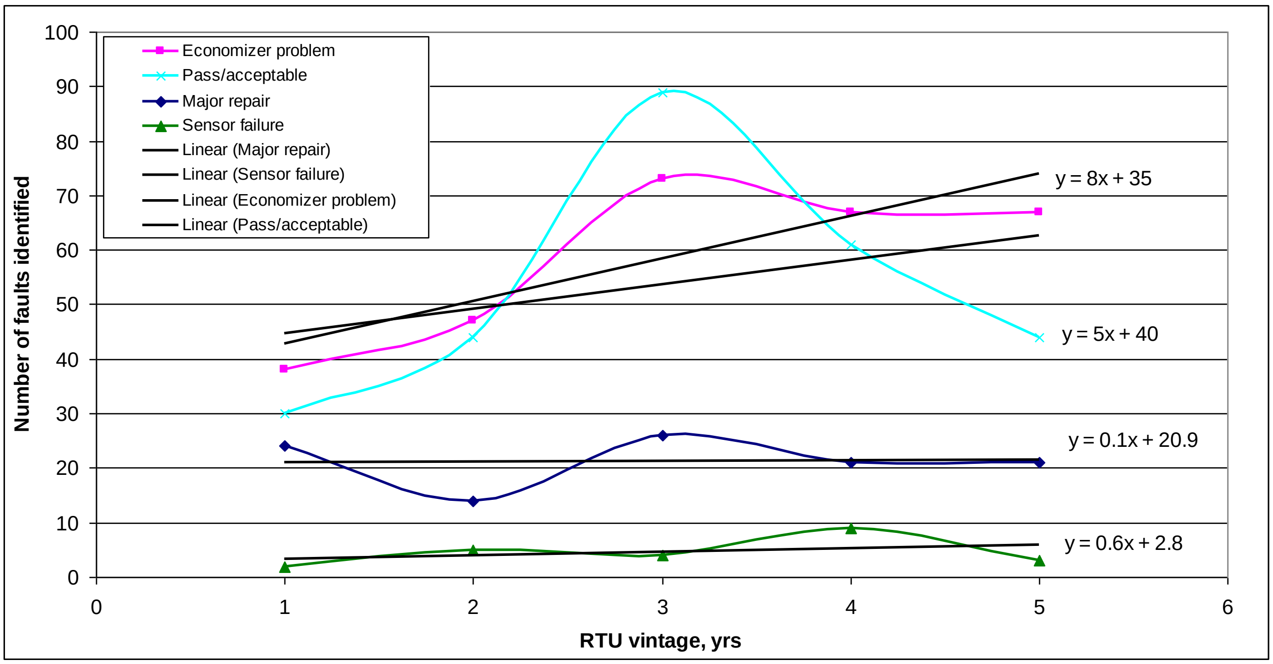


Figure 19 Faults by RTU Vintage: Economizer and Sensor Faults

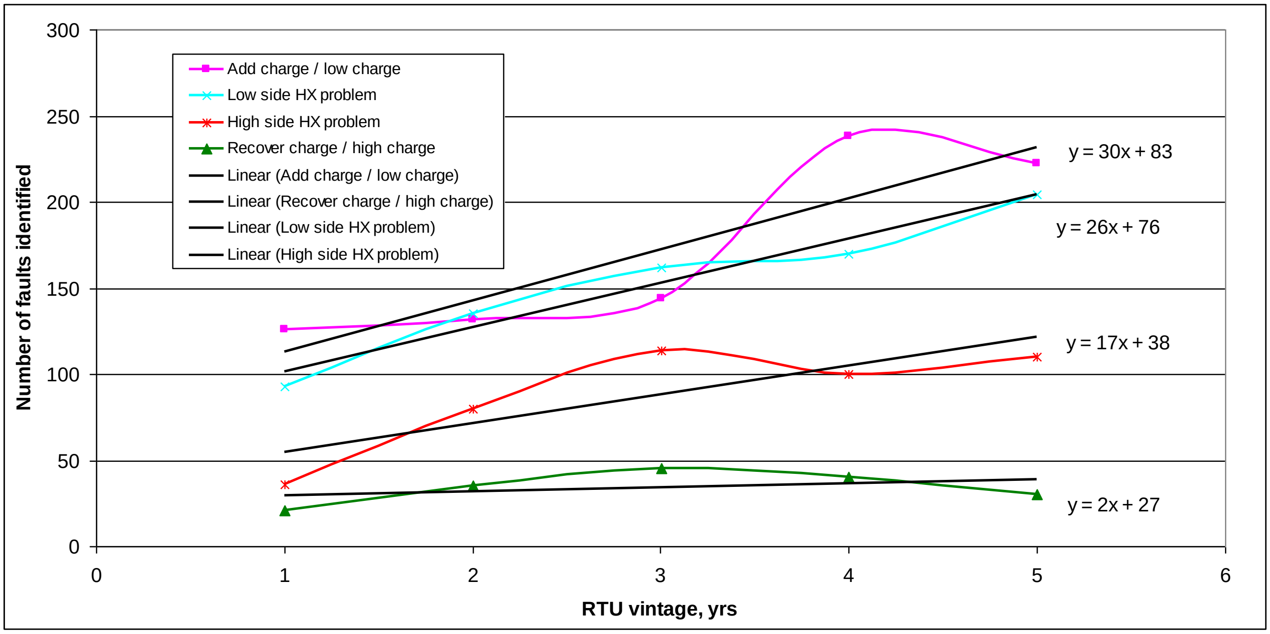


Figure 20 Faults by RTU Vintage: Refrigerant and Heat Exchange Faults

	Pass/ acceptable	Major repair	Add charge / low charge	Recover charge / high charge	Low side HX problem	High side HX problem	Economizer problem	Sensor failure
Slope (faults/yr)	5	0.1	30	2	26	17	8	0.6
Units tested/yr	527	527	527	527	527	527	251	527
Incidence	0.9%	0.0%	5.7%	0.4%	4.9%	3.2%	3.2%	0.1%
x 15 yrs analysis period	14%	0%	85%	6%	74%	48%	48%	2%

Figure 21 Summary of Fault Incidence Analysis

This analysis still assumes a 100% chance of the FDD system detecting the fault, and a 0% chance the fault would be detected without an FDD system. In reality, not all units will experience all these faults. The chance of the FDD system detecting the fault is closer to 75%. The chance the fault would be detected without an FDD system varies depending on typical service and if the fault impacts comfort conditions.

The following fault is quite likely detected by the economizer acceptance test or through regular service such that the fault is 75% likely to be detected:

- Economizer high-limit setpoint 55˚F instead of 75˚F

The following fault is likely detected through regular service and/or impact comfort conditions such that the fault is 50% likely to be detected:

- Refrigerant charge: 80% of nominal charge

The following list of faults are less likely detected through regular service and do not impact comfort conditions such that the fault is 25% likely to be detected.

- OAT sensor malfunction
- Compressor short cycling

- Refrigerant line restrictions/TXV problems
- Refrigerant line non-condensables
- Low side HX problem incl. low airflow (50% evaporator coil blockage)
- High side HX problem (50% condenser coil blockage)
- Economizer stuck closed
- Economizer stuck open

Figure 22 summarizes the results of the probability analysis. The FDD benefit is the difference between the probability of detecting the fault with FDD and the probability of detecting the fault without FDD.

Failure Mode	Fault incidence (over 15 years)	Prob. of detecting the fault w/FDD	Prob. of detecting the fault w/o FDD	Fault incidence x FDD benefit
Air temperature sensor malfunction	2%	75%	25%	1%
Refrigerant charge: 80% of nominal charge (-15% EER)	85%	75%	50%	21%
Compressor short cycling	30%	75%	25%	15%
Refrigerant line restrictions/TXV problems	62%	75%	25%	31%
Refrigerant line non-condensibles (-8% EER)	50%	75%	25%	25%
Low side HX problem incl. low airflow (50% evaporator coil blockage; -5% EER)	74%	75%	25%	37%
High side HX problem (50% condenser coil blockage; -9% EER)	48%	75%	25%	24%
Not economizing when it should (high-limit setpoint 55F instead of 75F)	30%	75%	75%	0%
Damper not modulating	24%	75%	25%	12%
Excess outdoor air	24%	75%	25%	12%

Figure 22 Summary of FDD Probability Analysis

Energy Savings

In the end, it was decided to shorten this list of faults. This proposal and thus the energy savings consist of only a subset of the analyzed faults. In particular, it includes only the faults that both the third party FDD systems and the HVAC OEMs can currently detect as of April 2011. The FDD system shall detect the following faults:

- Air temperature sensor failure/fault
- Low refrigerant charge
- Not economizing when it should

- Economizing when it should not
- Damper not modulating
- Excess outside air

Linear regression is used per climate zone and building type to determine the savings associated with the failure modes described by the EER penalty that were not simulated. The results of the probability analysis are applied to the energy savings results per climate zone and building type by multiplying the savings for each failure mode by the last column in Figure 22 (Fault incidence x FDD benefit). This yields the benefit of FDD considering the fault incidence and the probability of detecting the faults with and without an FDD system. These savings are then summed by climate zone and building type across all failure modes. Detailed energy savings results are provided in Appendix B: Energy Savings for FDD.

The Present Value (PV) energy savings over the effective useful life (EUL) of 15 years is $1,629 per RTU for a 54,000 Btu/h unit. The average first year energy savings is 852 kWh per RTU for a 54,000 Btu/h unit. The first year and 15-year statewide savings realized by implementing this measure are presented in Figure 23. To estimate statewide electricity savings the savings per building type and climate zone are divided by the building square footage and multiplied by the new construction estimate for the year 2014[xx] for the given climate zone and building type. These values are then summed over all the climate zones to yield the statewide savings. The only difference in the 15 year electricity savings calculation is the new construction estimates for the years 2014 to 2020 are used. The 2020 estimate was multiplied by 9 to estimate savings beyond the year 2020 and result in 15 years total.

Statewide Savings	Electricity Savings (kWh)	TDV Total $
1st Year Savings	10,132,610	$1,764,090
15 Year Savings	30,928,493	$20,992,673

Figure 23 FDD Statewide Savings

Maintenance Savings

Braun and Li report, "A technician will only detect and diagnose severe and obvious faults. In the absence of preventive maintenance, technicians would typically be called to perform emergency service when an air conditioner is not working or is unable to maintain comfort. Even if preventive maintenance is performed, the procedures only involve routine checks that can only detect severe and obvious faults. If an automated FDD system were applied, most (e.g, 75%) of the planned preventive maintenance inspection fees would be saved. One coil cleaning service can be saved per year through automated FDD."[xxi]

Li and Braun claim, "Automated FDD reduces service costs due to reduced preventive maintenance inspections, fault prevention, lower-cost FDD, better scheduling of multiple service activities, and shifting service to low season." A significant part of a service cost is the base visit fee. Through better scheduling of multiple service activities, the base visit fee can be shared across multiple faults on a single cooling system or multiple cooling systems of a site. Some combinations of services also allow cost savings. For example, any combination of faults that require recovering the refrigerant will prove a cost savings if addressed during a single visit. They conclude that $30/kW can be saved annually on the service costs.[xxii] To maintain a conservative analysis, we used 50% of this value, or $15/kW ($16/ton) annual maintenance cost savings for this measure. This yields a present value maintenance cost savings of $179/kW ($195/ton) at 1.09 kW/ton or $878 for a 54 kBtu/h unit.

Measure Cost

For our measure cost analysis we used information provided by Heinemeier, et al., who report, "Processing of diagnostic algorithms can take place in the onboard controller, on an installed PC, or remotely. Even when a PC or remote computer is used, there may still be a need for on-site signal processing to reduce the data and pre-process them. In most cases, these processing platforms do not contribute significantly to the cost. For some methods, however, it will be significant.

- High cost: An approach that uses an EMS platform for processing
- Moderate cost: An approach that that can be accomplished by an embedded controller
- Low cost: An approach that can be accomplished only with use of an added PC or processor

The defined scope for this program is remote diagnostics, so all approaches considered here will require remote communications. For remote diagnostics, communications hardware and access are required. This can be accomplished by tying into the building's Energy Management System, or installing a dedicated modem and phone line. It is often possible to use a gateway to allow the diagnostic module to piggy-back on the building's communications infrastructure to reach the internet."[xxiii]

The cost of the FDSI Sentinel and PNNL's Smart Monitoring and Diagnostic System (SMDS) FDD systems are in the range of $250 to $400 (OEM cost) or $1600 (building owner installed cost after factor of 4 mark-up). The cost of the Sensus MI system is $5,000 to $15,000 per building. The nature of this solution is such that this tool is best implemented at locations with many RTUs such as big box retail. Thus the cost per RTU is less than that of the FDSI Sentinel and the SMDS. For conservativeness, the highest cost of this suite of tools is used for the cost analysis, which is $1600/RTU. This cost includes many more faults than the list of five faults proposed here, thus continuing the list of conservative assumptions. Another reason why this is a conservative assumption is because the installed cost for the OEM solution is much less than $1600.

Sensus MI and FDSI Sentinel can detect all the faults on our proposed list. SMDS can detect all the faults except low airflow, refrigerant charge, and insufficient capacity.

With regard to PNNL's SMDS tool, "Battelle Pacific Northwest Division in collaboration with NorthWrite Inc. has developed a tool for continuously monitoring the condition and performance of packaged air conditioners and heat pumps. The Smart Monitoring and Diagnostic System (SMDS) is mounted in a small box installed on the side of each packaged air conditioner or heat pump and provides continuous remote monitoring and diagnostics for the unit. It requires the following components:

- Temperature sensor
- Data processing module
- Communication module (required for any FDD)

The SMDS works by constantly collecting data from sensors installed on the equipment to measure its performance and detect and diagnose problems with its operation. The unit then sends the results wirelessly, directly from each packaged unit to a network operations center, where the data are stored securely and information on the condition of each packaged unit is made available on the internet. The SMDS can be installed on new or existing packaged air conditioners and heat pumps."[xxiv]

Cost Effectiveness/LCCA

The total incremental cost is the sum of the incremental installed cost of $1,600 and the PV maintenance cost of - $878 for a total incremental cost of $722. As shown in Figure 24, the measure is cost effective for the proposed size threshold of 54 kBtu/h unit and larger.

Incremental Installed Cost	$1,600
Incremental Annual Maintenance, 54 kBtuh	($74)
PV of Annual Maintenance, 54 kBtuh	($878)
Total Incremental Cost, 54 kBtuh	$722
PV of Energy Savings, 54 kBtuh	$1,629
Lifecycle cost savings	$907
Benefit/Cost Ratio	2.3

Figure 24 FDD: Lifecycle Cost Results

Occupancy Sensor to Setback Thermostat

This measure requires an additional control sequence for built-up VAV systems or a thermostat that can accept an occupancy sensor input and has three scheduling modes (occupied, standby, and unoccupied) for packaged equipment. A thermostat with three scheduling modes works as follows. The unoccupied period is scheduled as usual for the normal unoccupied period, e.g. nighttime. The occupied period is scheduled as usual for the normal occupied period, e.g. daytime. When the morning warm-up occurs, the thermostat's occupied schedule is used to establish the heating/cooling temperature setpoints. Upon completion of the morning warm-up, the standby setpoint schedule on the thermostat is enabled. This schedule remains in effect until occupancy is sensed (then enabling the occupied setpoint schedule) or until the normally scheduled unoccupied period occurs. After the period of occupancy ends, e.g. a conference room is vacated, and when the time delay expires as programmed into the occupancy sensor, the standby setpoint schedule on the thermostat is enabled. Figure 25 shows an example of how the three scheduling modes might be programmed for a temperature setup/setback of 4˚F.

	Cooling, °F	Heating, °F
Occupied	73	70
Standby	77	66
Unoccupied	77	60

Figure 25 Example Thermostat Setpoints for Three Modes

Energy simulation

The simulation used a single space, various numbers of exterior surfaces, a range of setup/setback temperatures (1˚F, 1.5˚F, 2˚F), and a range of standby period durations. In addition, the simulation was completed for three different primary HVAC system types, six climate zones, and three space types. Specifics of the simulation parameters are described below. The HVAC system types considered in this analysis were packaged CAV, packaged VAV, and built-up VAV systems which is consistent with the Non Residential New Construction Baseline Study.[xxv]

The primary energy savings that accrue from temperature setup/setback are from the reduction in space loads due to cycling the fans off during standby periods in the packaged CAV system or closing the zone damper in the case of the packaged and built-up VAV systems. An additional source of energy savings is reduction in the temperature difference across the exterior surfaces, and the resulting reduction in heat transfer. Therefore, the parameters of interest are climate zone, number of exterior walls, degrees of setback, and the duration of the standby period. In addition, because this measure is related to multipurpose rooms, conference rooms, and classrooms, additional parameters include building type and HVAC system type.

A single space simulation model was used to represent the HVAC controlled room. The single space was modeled with varying numbers of exterior surfaces ranging from zero to three and represents one room in a larger building hence the lack of a four exterior surface space. The single space with zero, one and two exterior surfaces represents spaces with conditioned space above and below. The three exterior surfaces space represents a space in the corner of a building on the top floor, but with conditioned space below.

There are three zones of interest with varying inputs: Large conference room with DCV, small conference room with occupancy controlled lighting, and classroom or multipurpose room with occupancy controlled lighting. The inputs are listed below per zone of interest. The occupancy density and ventilation rates are based on 2008 Title 24 compliance rates. The weekday occupancy schedule of the school is meant to include hours to compensate for potential after school activities and teacher preparation time.

Large conference room with DCV:

- Area 15 ft. by 25 ft. (375 ft^2)
- Occupancy schedule: 8 a.m. to 6 p.m. five days a week, annually
- Occupancy density 30 ft^2/person
- Ventilation rate 0.15 cfm/ ft^2

Small conference room:

- Area 15ft. by 10 ft (150 ft^2)

- Occupancy schedule: 8 a.m. to 6 p.m. five days a week, annually
- Occupancy density 30 ft^2/person
- Ventilation rate 0.5 cfm/ ft^2

Classroom or multipurpose room:

- Area 15 ft. by 25 ft. (375 ft^2)
- Occupancy schedule: 8 a.m. to 6 p.m. five days a week for nine months of the year
- Occupancy density 20 ft^2/person
- Ventilation rate 0.5 cfm/ ft^2

The overarching model parameters were:

- Climate zones: 3, 6, 9, 12, 14, 16
- Number of exterior walls: 0, 1, 2, 3
- Duration of the standby period: 1, 2, 4, 10 hours
- Temperature setup and setback: 0°F (baseline), 1°F, 1.5°F, 2°F
- System type: packaged single zone CAV with gas furnace, packaged VAV with a boiler, built-up VAV system with boiler and centrifugal chiller

The particular climate zones were chosen because they reasonably represent the climatic variation found throughout the state. The standby (unoccupied) period began at noon, except for the "all day" case of 10 hours. In the "all day" case, it is assumed that the system still goes through the morning warm-up process and the standby period begins at 8 a.m. The schedules used full occupancy (i.e. design occupancy) with lighting and equipment at 100% during the occupied period. During the standby period, occupancy and lighting were zero, with equipment at 5%. This represents the energy consumption of electronic devices in the room such as computers, projectors, and other audio visual equipment. Four temperature set point change values and four standby periods were chosen for the simulation in order to determine the relationship between setup/setback, duration of the standby period, and energy savings.

The nominal temperature set point schedules per the 2008 Nonresidential ACM Approval Method[xxvi] were used in the models and are listed below:

- Cooling: 73°F – 7 a.m. to 6 p.m. Monday to Friday, 81°F all other time
- Heating: 70°F – 7 a.m. to 6 p.m. Monday to Friday, 60°F all other time

Exterior walls used insulation to provide the climate specific U-values specified in 2008 Title 24 Table 143-A. This table was also used for the glazing U-values and SHGC values. For surfaces that were not "exterior", the same construction was used with insulation R-value set to 999, making the surface adiabatic. Floor construction used insulation with R-999. Infiltration was 0.0973 cfm/ft^2, and the following parameters were the eQUEST defaults.

Exterior wall construction was:

- 1 in. stucco
- 5/8 in. plywood
- Board insulation (varied by climate zone)
- Framing with batt insulation (R-7.2)
- ½ in. gypsum board

Roof Construction was:

- Built-up roofing
- Board insulation (varied by climate zone)
- 5/8 in. plywood
- Airspace (R-1)
- ½ in. acoustic tile

Glazing was placed on all exterior surfaces, with the SHGC appropriate to the climate zone. This was done so that solar heat gains would be equally distributed across all four directions, thus effectively addressing the issue of orientation without having to rotate the model. The window size was set to be 35% of the exterior wall area, i.e., there is more window area when two walls are exterior than when there is only one exterior wall.

The most important parameter is the heat transfer across the exterior wall(s). The heat transfer across interior walls will not be significant because any heat transfer that does occur will simply result in the transfer of load from one system or thermal zone to an adjacent one. Also, since the space going into setback will have a temperature between the outdoors and the adjacent space, any heat transfer across the interior surfaces will counteract heat transfer with the exterior, thereby mitigating the value of the measure.

For the "one exterior surface" case, the exterior wall was the north facing, long wall. For the "two exterior surface" case, the east facing short wall was also made exterior. For the "three exterior surface" case, the roof was made exterior. It is possible that a 90° rotation, putting the long sides of the space facing east and west may have some impact, but it would be negligible.

The CAV case used a packaged single zone RTU. Cooling efficiency (EIR) was 0.2332 with the gas furnace having an HIR of 1.24. The packaged VAV unit had the same cooling efficiency and a gas hot water boiler for reheat with an HIR coefficient of 1.24. The built-up VAV system used a centrifugal chiller with a COP of 5 and a natural gas hot water boiler with 80% AFUE. These values are the minimum efficiency values for 2008 Title 24 compliance. Both units used economizers with the following parameters based on the Demand Control Ventilation (DCV) Measurement Guide:[xxvii]

- ECONO-LIMIT-T = 55˚F
- ECONO-LOCKOUT = YES (Specifies that the economizer and the compressor cannot operate simultaneously. If the economizer cannot handle the entire cooling load, then mechanical cooling will be enabled and the economizer will return to its minimum position. This control sequence is equivalent to what the California Energy Commission calls a non-integrated economizer.)
- OA-CONTROL = OA-TEMP
- MAX-OA-FRACTION = 0.5

The CAV case was modeled as one zone. The VAV cases used a zone multiplier of nine for a total of 10 zones in the model. Only one zone had the unoccupied periods applied, while the other nine zones used the fully occupied schedule. The additional nine zones also had the single north wall set as exterior, and the window size set to 35% of the single exterior wall.

Temperature Recovery and Impact on Human Comfort

The simulation results alone do not account for human comfort. This should be considered as this measure relates to setting up or setting back the temperature during the day in an otherwise occupied building. When the zone becomes occupied after an unoccupied or standby period, some amount of time is needed for the zone to recover from the setup or setback and reestablish its occupied temperature set point (recovery time). A short monitoring effort and a manual calculation were undertaken to estimate the typical recovery time associated with this situation. This was done because there was a lack of published recovery time data and the hourly interval of the simulation wouldn't give the resolution required. The monitoring effort examined two of the four zone types included in the energy simulation: 1) a zone with one exterior surface (1 exterior wall) and 2) an interior zone with no exterior surfaces (0 exterior walls). The average recovery time was then extrapolated to the other setback temperatures and zone types included in the energy simulations. This data in addition to human comfort requirements, as specified by ASHRAE Std 55-2004,[xxviii] will be used to account for human comfort issues and limit the setup/setback temperatures considered in the cost effectiveness analysis.

Supply air temperature and room air temperature data was gathered in two conference rooms during the short monitoring effort. One is an interior room while the other has one exterior wall. These conference rooms do not have occupancy sensors to command the HVAC temperature set points so we observed the zone temperature recovery time during the morning warm-up period. One minute interval data was gathered for two days in the conference rooms. The HVAC system is a VAV system set to maintain a duct static pressure of 1.5 in. w.g. Both the room temperature and the supply air temperature were monitored with portable, battery-powered dataloggers. This data was then reviewed to determine the occupied (daytime) and unoccupied (nighttime) temperature set points. From the data it was determined that the occupied set point for the interior zone was 72˚F and for the 1-exterior wall zone it was 70˚F. Also from the monitored data it was determined for both rooms that the cooling setup set point (unoccupied mode) is two degrees above the occupied set points.

The morning period beginning with the minute the supply air temperature equals the room air temperature is a reasonable proxy for a single zone packaged rooftop unit recovering from a temperature setup or setback in terms of HVAC and zone dynamics. The minute where the supply air temperature equals the room air temperature was considered the start point for calculation of the recovery time. The minute when the room air temperature reaches the occupied set point was considered the end point for the recovery time calculation. The figure below shows the start-up period and the starting and ending points for the 1-exterior wall case on the first day of monitoring.

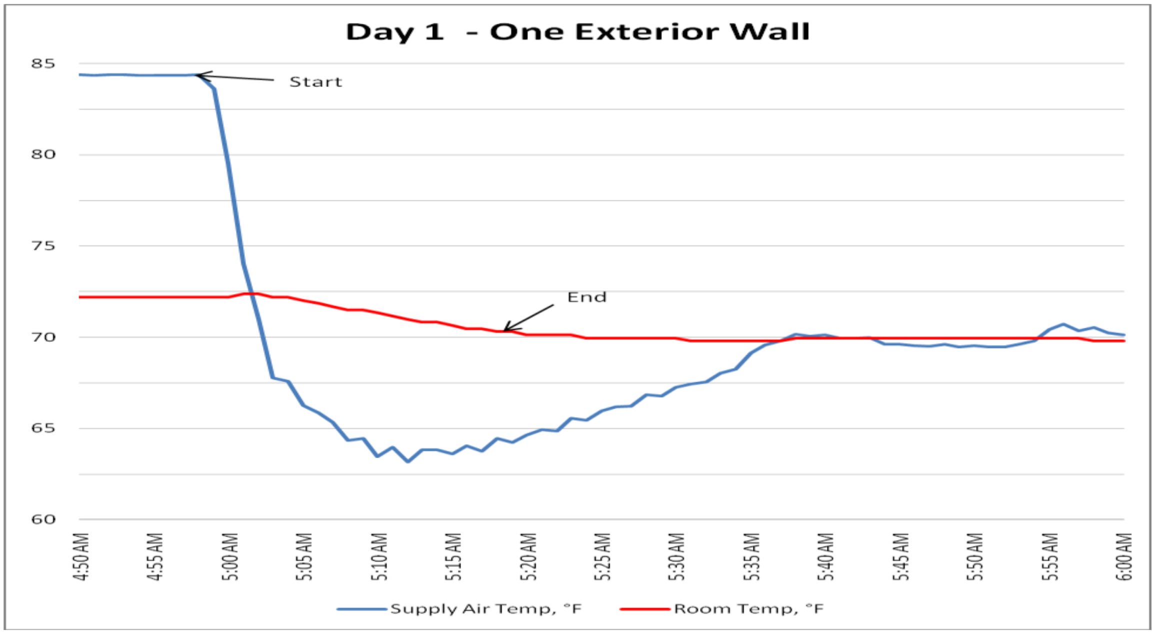


Figure 26 Monitoring of Conference Room: Temperature Profiles

The average recovery time for the 2˚F setup for the interior zone was 12.8 minutes and for the 1 exterior wall zone it was 16.0 minutes as shown in the following table.

Zone	Day	Recovery Time (min)	Day Set Point (°F)	Night Set Point (°F)	Setup (°F)	Average Recovery Time (min)
Interior	1	12.0	72	74	2	12.8
Interior	2	13.5	72	74	2	
One Exterior Wall	1	14.5	70	72	2	16.0
One Exterior Wall	2	17.5	70	72	2	

Figure 27 Monitoring of Conference Room: Average Recovery Time

A few critical building and HVAC system parameters associated with the conference rooms and the simulation are shown in Figure 28. All values associated with the conference room were measured unless otherwise specified. All values associated with the simulation are averages of the VAV system simulation. The VAV box damper in the conference rooms should be fully open or almost fully open during the morning startup period, thus this HVAC system is also a reasonable proxy for the single zone CAV system that was included in the energy simulation. In general this table shows that the parameters associated with the field study reasonably match those of the energy simulation zone therefore, the results of this study can be applied to the simulation results.

System Parameter	Conference Room		Simulation
	Interior	One Exterior Wall	One Exterior Wall
Window/wall Ratio	n/a	58%	35%
Supply cfm	210*	398*	462
Floor area (sf)	210	398	375
Height of zone (ft)	8.5	8.5	8.5
Duct static pressure set point (in. w.g.)	1.50	1.50	1.25
Time to complete 1 air change (min)	8.5	8.5	6.9

Figure 28 Monitoring of Conference Room: System Description

*Supply airflow was measured during the day and damper position was estimated to approximate this result

Impact on Human Comfort

The recovery times from Figure 27 were extrapolated to the remaining simulation scenarios. The time it took each scenario to recover from a setback of 2, 4, and 8 ˚F is indicated in the following table. The recovery time ranges from 13 to 118 minutes depending on the number of exterior surfaces and the setup temperature. The recovery time ranges from 13 to 23 minutes for a 2˚F setup, 26 to 45 minutes for a 4˚F setup, and 51 to 90 minutes for an 8˚F setup.

Zone	# Exterior Surfaces	min/°F	Set up (°F)	Estimated Recovery Time (min)
Interior	0	6.4	2	13
Interior	0	6.4	4	26
Interior	0	6.4	8	51
One Exterior Wall	1	8	2	16
One Exterior Wall	1	8	4	32
One Exterior Wall	1	8	8	64
2 Exterior walls	2	9.6	2	19
2 Exterior walls	2	9.6	4	39
2 Exterior walls	2	9.6	8	77
2 Exterior walls & roof	3	11.3	2	23
2 Exterior walls & roof	3	11.3	4	45
2 Exterior walls & roof	3	11.3	8	90

Figure 29 Temperature Setup and Recovery Time per Zone Type

Because this measure relates to setting up or setting back the temperature in conference rooms and classrooms for standby periods (unoccupied periods of the day), the recovery time and rate of temperature change is critical to human comfort. ASHRAE Std 55-2004 was used to determine the outer bounds for the standby period as illustrated in the figures below. Spaces where the occupants'

Met is between 1 and 1.3 and the clothing insulation is between 0.5 and 1.0 (such as conference rooms and classrooms) and using an assumed RH of 30% to 60% (HVAC Systems and Equipment ASHRAE Handbook)[xxix], yields a lower bound of 67.5˚F for 60% RH and 69˚F for 30% RH, an average of 68.25F. The upper bound according to this graph is 77˚F for 60% RH and 81˚F for 30% RH, an average of 79˚F. These values represent the outer temperature bounds for the standby period because when someone enters the room they should be comfortable before the room reaches the occupied temperature. The occupied set point for the simulations was 73˚F cooling and 70˚F heating as prescribed in the 2008 Non Residential ACM Approval Method.[xxvi] So the maximum setback (heating) temperature would be 2˚F (70˚F minus 68˚F) and the maximum setup temperature (cooling) would be 6˚F (79˚F minus 73˚F) to remain within the human comfort bounds. The simulation occupied and unoccupied cooling and heating set points and the proposed maximum standby set points are shown overlaid on the ASHRAE Std 55 comfort chart showing the human comfort range in Figure 30 and Figure 31.

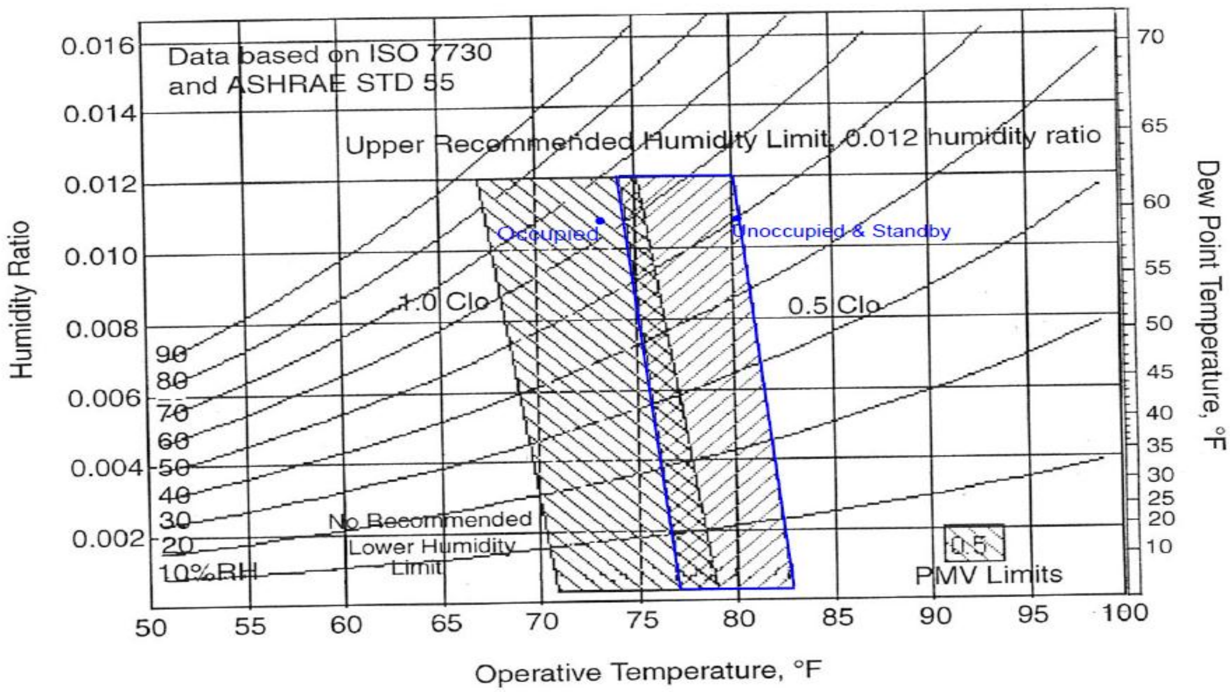


Figure 30 Cooling Set points Plotted on ASHRAE Std 55 Comfort Chart

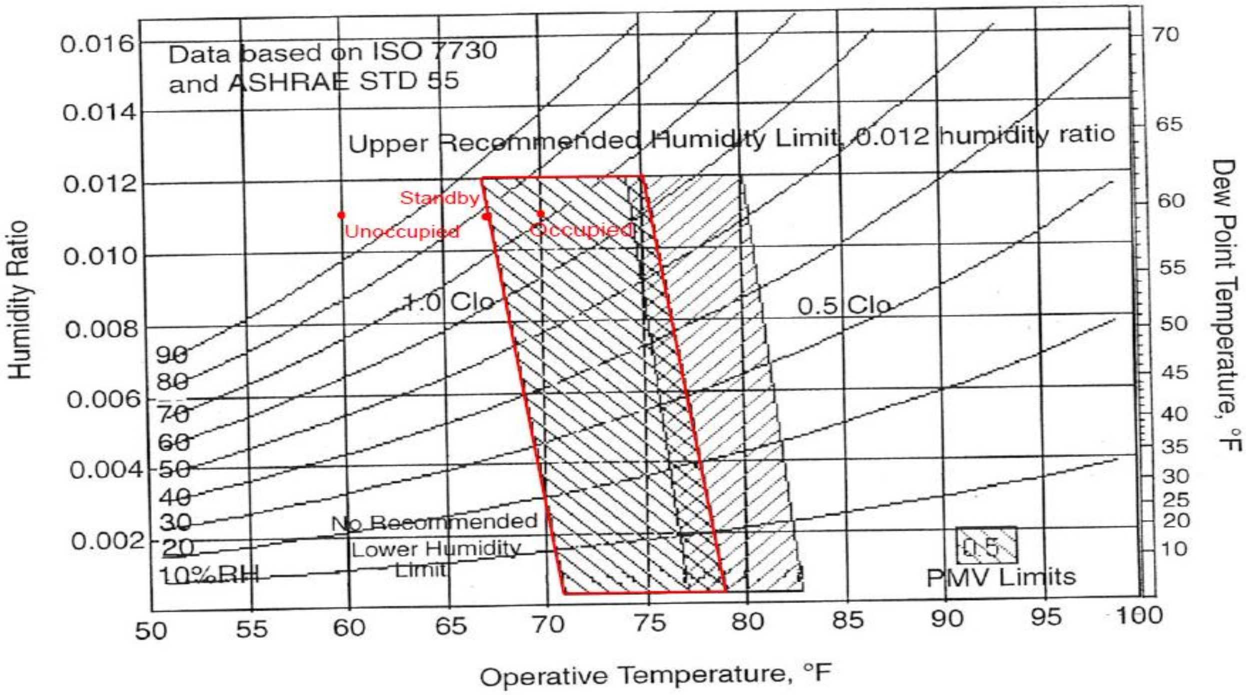


Figure 31 Heating Set points Plotted on ASHRAE Std 55 Comfort Chart

The figure below shows the recovery time for each zone type with the air change values calculated from Figure 28. The simulated (simulation – air change) and the monitored (monitored conference room – air change) lines in the plot assume that in one air change the temperature could change enough to meet even the 8˚F setup/setback case. This represents the lower bound of the recovery time; it was calculated based solely on the supply air flow rate and the volume of the room. The highlighted areas represent the acceptable setup and setback temperatures and associated recovery times to meet human comfort needs as described in the above paragraph.

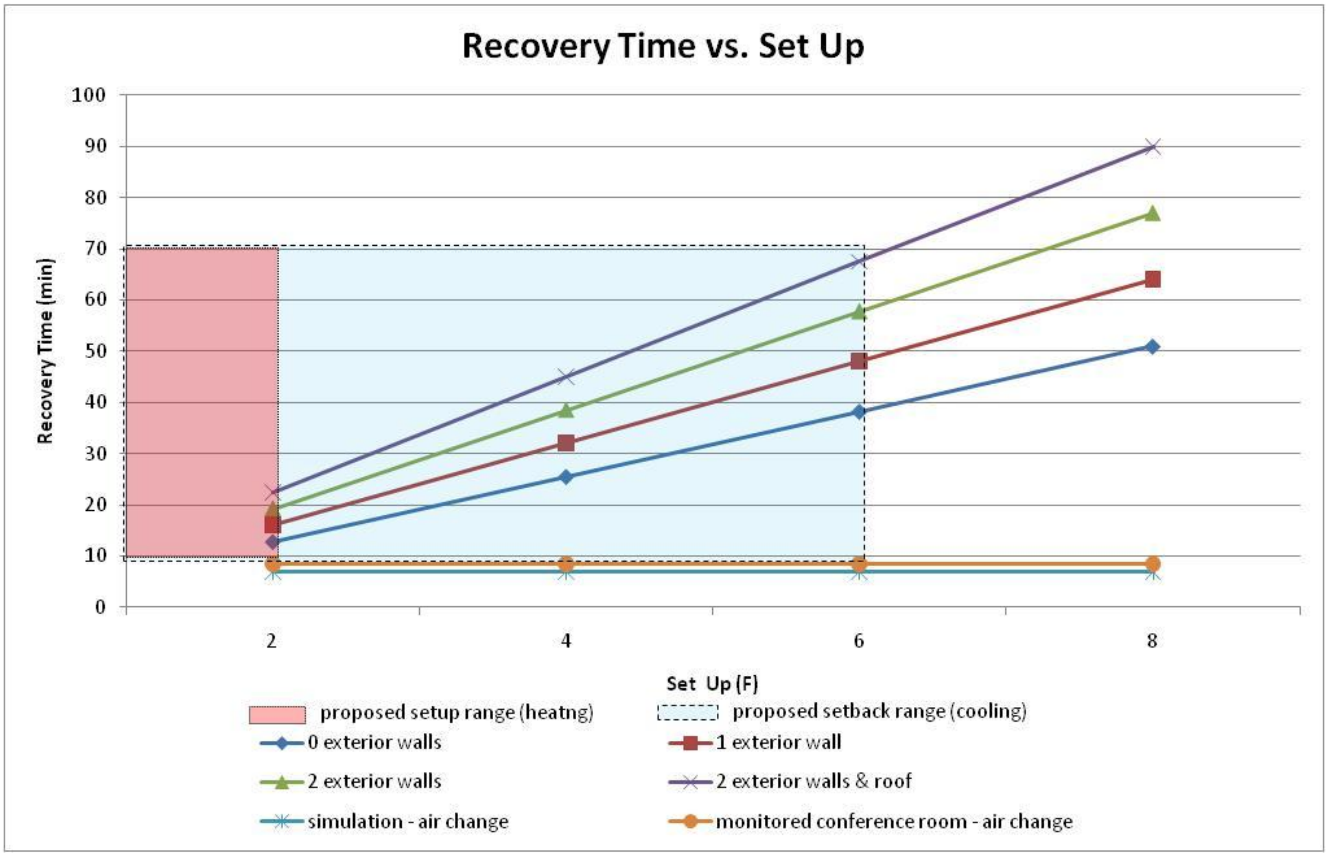


Figure 32 Temperature Setup and Recovery Time per Zone Type

At 2˚F the recovery time ranges from 13 to 23 minutes depending on the number of exterior walls. At 6˚F the recovery time ranges from 38 to 68 minutes. The maximum setup is 6˚F and the maximum setback is 2˚F in order to meet human comfort requirements. The simulation setback and setup maximum is 2˚F, which is well within the human comfort range for both heating and cooling.

Cost Analysis

The following tables provide a summary of the costs for some typical, available, commercial thermostats with two stages of cooling. The listed cost is for the equipment only (labor is excluded).

Manufacturer	Model	Cost
White Rodgers	1F95-1280	$239
Pro1IAQ	T955W	$179
White Rodgers	1F95-0680	$179
Honeywell	TB8220U1003	$169
White Rodgers	1F93-380	$161
Aprilaire	8570	$148
	Average	**$179**
	Median	$174

Figure 33 Multi-stage Thermostats without Occupancy Sensor Input

Manufacturer	Model	Cost
Honeywell	T7350D1008	$450
Victronics	VZ7656B	$414
Honeywell	T7351F2010	$365
Jenesys	VT7600	$350
Venstar	T1900	$143
Venstar	T2900	$139
	Average	**$310**
	Median	$358

Figure 34 Multi-stage Thermostats with Occupancy Sensor Input

The price differential between the average costs of thermostats with and without an occupancy sensor input is $131, which we use for the incremental equipment cost. The incremental installation costs must also be considered. The results of the manufacturers' survey indicate a typical incremental installation time is 30 minutes for new construction and 1.5 hours for retrofit. At $94.76 per hour per RS Means (CA costs including overhead and profit) for an electrical contractor, this is $47.38 for new construction and $142.14 for retrofit. The total installed incremental measure cost is $178.38 for new construction and $273.14 for retrofit.

The new construction installation includes running a signal wire between the occupancy sensor and the thermostat and reviewing (and programming if needed) the standby schedule setpoints. Additional time is needed during a retrofit installation due to more difficult access for running the signal wire in areas without disturbing the surface finishes on the walls. Depending on space constraints and the location of the occupancy sensor and the thermostat, a typical incremental installation time may be 1.5 hours for a retrofit installation.

With regard to the built-up VAV system, a conservative incremental measure cost is $250 per communication with stakeholders. This includes parts and labor to install a 24 VDC HVAC occupancy sensor, wire it to the VAV box, and implement a control sequence to close the box damper during unoccupied periods.

The time dependent valuation (TDV) of the energy savings was determined in order to compare the total cost of the occupancy sensors to the cost savings of the sensors. The Life Cycle Cost Methodology[xxx] was modified slightly for this analysis because the actual start time of the standby period was not a variable in the simulation and in reality could occur at any time during the nominal occupancy period. Instead of applying the hourly TDV to the hourly simulation output files, an average TDV was applied for the time period when standby conditions could occur (8 a.m. to 6 p.m weekdays). This method was employed to offset the assumption that the standby period would begin at noon. TDV values are generally higher in the afternoon when generation capacity is at its limit so applying the hourly TDV values would likely result in overestimation of cost savings results.

The total cost of the occupancy sensor for HVAC control (described above) was compared with the resulting TDV cost of the energy savings. The setup and setback ranges from the human comfort study (described above) limited the ranges to a 2˚F setback (heating) and a 6˚F setup (cooling). By comparing the costs, the relative importance of each of the simulation variables (climate zone, system type, building type, number of exterior walls, and degrees of setback) was determined. Occupancy Sensor Simulations and Energy Analysis for Commercial Buildings[xxxi] was used to determine the typical duration and frequency of the standby period. This data was used in combination with the cost effectiveness analysis to determine the appropriate temperature setback to meet both the cost effectiveness and human comfort requirements.

Results

Energy savings were calculated per a number of simulated parameters including building type, climate zone, system type (packaged CAV, packaged VAV, built-up VAV), number of exterior surfaces (0-3), degrees of setback (1.0˚F, 1.5˚F, 2.0˚F), and unoccupied period (1, 2, 4, 10 hours). We used the average TDV value calculated by taking the average TDV over the nominal occupied period (8am-6pm M-F). This average TDV was multiplied by the energy savings to produce a type of average TDV savings due to a given duration of non-occupancy without knowing exactly when the non-occupancy occurs. Otherwise, the results can be quite varied if the non-occupancy is in the morning (no TDV peaks) or afternoon (many TDV peaks). This method offsets the assumption that the unoccupied hour starts at noon as used in the simulation.

Average total TDV savings per unoccupied period for each setback, zone type and HVAC control method are shown in Figure 35.

Setback (Heating & Cooling)	HVAC Control	Zone Type	Average Total TDV Savings Per Zone (kbtu)			
			1 hr	2 hr	4 hr	10 hr
1F	DCV	Large Conference Room	1,726	3,538	7,285	16,612
1.5F	DCV	Large Conference Room	3,310	5,948	11,468	24,140
2F	DCV	Large Conference Room	5,571	8,949	16,238	31,010
1F	Occ. Sensor	Small Conference Room	927	1,862	3,702	8,385
1.5F	Occ. Sensor	Small Conference Room	1,688	3,001	5,761	12,180
2F	Occ. Sensor	Small Conference Room	2,756	4,437	8,027	15,678
1F	Occ. Sensor	Classroom or Multipurpose Room	1,561	3,199	6,193	13,340
1.5F	Occ. Sensor	Classroom or Multipurpose Room	2,893	5,254	9,744	19,503
2F	Occ. Sensor	Classroom or Multipurpose Room	5,234	8,253	14,168	25,201

Figure 35 Average Total TDV Savings per Scenario

The highlighted red cells represent those scenarios where the average total TDV savings is cost effective (i.e. above the minimum total TDV savings required for cost effectiveness. The minimum TDV savings required for cost effectiveness is the total measure cost divided by the 15 year statewide present value of energy 0.089 $/TDV kBtu[xxxii], which yields 2,004 kBtu for the occupancy controlled HVAC system and 2,808 kBtu for the DCV controlled HVAC system.

The number of red cells in Figure 35 for all HVAC control cases indicates that, as expected, the cost effectiveness increases with magnitude of cooling setup and increased length of the standby period.

These results assume that the unoccupied period occurs once a day Monday to Friday sometime between the hours of 8 a.m. and 6 p.m. annually, or in the case of the school from September to June (9 months). The savings depend on the duration of the vacancy event. The savings resulting from a single two-hour vacancy is different than two one-hour vacancy events. To determine the savings for multiple vacancy events, the simulation results of the specified event duration are multiplied by the number of vacancy events. For example, the savings generated by two 1-hour vacancy events is double the savings of the 1-hour case, which is higher than the savings from a single 2-hour vacancy event.

The typical duration of an unoccupied period for classrooms and conference rooms is an important criterion with respect to the energy savings. *Occupancy Sensor Simulations and Energy Analysis for Commercial Buildings*[xxxiii] describes typical unoccupied durations for classrooms and conference rooms. This report indicates that classrooms are unoccupied for a total of 6.22 hours a day and conference rooms are unoccupied for 7.22 hours a day. These values represent metered data collected by occupancy sensors over the course of two weeks for 31 classrooms and 26 conference rooms. The unoccupied periods may occur in shorter intervals of closer to two hour each throughout the day rather than a continuous six or seven hour period. Information on the exact length of the unoccupied period is not available. As a conservative estimate, we constrain the analysis to two two-hour vacancy events. The results are shown in Figure 36.

Zone Type	HVAC System Type	Average Total TDV Savings Per Zone : 2F 2 x 2-hr vacancy periods	
		(kbtu)	($)
Large Conference Room	Packaged CAV	1,180	$105
Large Conference Room	Packaged VAV	21,480	$1,910
Large Conference Room	Built-up VAV	31,035	$2,759
Small Conference Room	Packaged CAV	592	$53
Small Conference Room	Packaged VAV	10,431	$927
Small Conference Room	Built-up VAV	15,601	$1,387
Classroom or Multipurpose Room	Packaged CAV	1,045	$93
Classroom or Multipurpose Room	Packaged VAV	19,150	$1,702
Classroom or Multipurpose Room	Built-up VAV	29,321	$2,607

Figure 36 TDV Savings for Occupancy Sensor Measure

This proposed code addition requires thermostat temperature setpoint setup/setback when a zone is unoccupied. This applies to multipurpose rooms of less than 1,000 sf, classrooms, and conference rooms. The temperature setpoints in standby mode shall be no higher than 68˚F heating and no lower than 75˚F cooling.

The Present Value (PV) energy savings over the effective useful life (EUL) of 15 years is $1,882 per controlled zone, on average for the packaged VAV and built-up VAV systems. The TDV energy savings is 21,170 kBtu per controlled zone, on average for the packaged VAV and built-up VAV systems. The first year and 15-year statewide savings realized by implementing this measure are presented in Figure 37. The statewide savings assumes 26% of the school area is classroom, 4% of the office area is conference room and 5% of the school area is multipurpose room[xxxiv]. This information and the average school and office area were gathered from the prototype building data in the Database for Energy Efficiency Resources. Detailed energy savings results for the two building types are provided in Appendix C: Energy Savings for Occupancy Sensors. The first year and 15-year statewide savings realized by implementing this measure are presented in Figure 37.

Statewide Savings	Electricity Savings (kWh)	TDV Total $
1st Year Savings	6,959,128	$1,530,923
15 Year Savings	116,399,424	$18,217,986

Figure 37 Occupancy Sensor Statewide Savings

Cost Effectiveness

No incremental maintenance costs are expected relative to the base case. As shown in Figure 38, this measure is cost effective for packaged VAV and built-up VAV, but not for packaged CAV systems.

	Large Conference Room			Small Conference Room			Classroom or Multipurpose Room		
	Packaged CAV	Packaged VAV	Built-up VAV	Packaged CAV	Packaged VAV	Built-up VAV	Packaged CAV	Packaged VAV	Built-up VAV
Incremental Installed Cost	$178	$250	$250	$178	$250	$250	$178	$250	$250
Incremental Annual Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Incremental Cost	$178	$250	$250	$178	$250	$250	$178	$250	$250
PV of Energy Savings	$105	$1,910	$2,759	$53	$927	$1,387	$93	$1,702	$2,607
Lifecycle cost savings	($73)	$1,660	$2,509	($125)	$677	$1,137	($85)	$1,452	$2,357
Benefit/Cost Ratio	0.6	7.6	11.0	0.3	3.7	5.5	0.5	6.8	10.4

Figure 38 Occupancy Sensor: Lifecycle Cost Results

Two-Stage Thermostat

This proposed measure is a mandatory requirement for a thermostat that allows for two stages of cooling for single zone systems whenever an economizer is present. The base case is a single stage thermostat.

Cost Analysis

The following tables provide a summary of the cost for some typical, available, commercial thermostats with one or more stages of cooling. The listed cost is for the equipment only (labor is excluded).

Manufacturer	Model	Cost
Honeywell	T7350A1004	$175
RobertShaw	9901i	$158
RobertShaw	300-203	$139
White Rodgers	1F97-1277	$124
RobertShaw	300-206	$95
LuxPro	PSP721U	$79
	Average	**$128**
	Median	$131

Figure 39 Single-stage Thermostats

Manufacturer	Model	Cost
White Rodgers	1F95-1280	$239
Pro1IAQ	T955W	$179
White Rodgers	1F95-0680	$179
Honeywell	TB8220U1003	$169
White Rodgers	1F93-380	$161
Aprilaire	8570	$148
	Average	**$179**
	Median	$174

Figure 40 Multi-stage Thermostats

The price differential between the average costs of single-stage and multi-stage thermostats is $51, which we use for the incremental equipment cost. The incremental installation costs must also be considered. The results of the manufacturers' survey indicate a typical incremental installation time is 45 minutes for new construction. This includes running a signal wire between the economizer and the thermostat. At $94.76 per hour per RS Means (CA costs including overhead and profit) for an electrical contractor, this is $71.07. The total installed incremental measure cost is $122.07 for new construction.

This measure is also useful as a retrofit; however, we find in the field that 37% of RTUs do not have enough wires to allow two-stage cooling. In effect this means the money spent on a new two-stage thermostat is wasted on these RTUs if the wiring is not upgraded.

To get proper savings from a two-stage thermostat and an outside air economizer, there must be enough thermostat wires to allow the economizer to be the first stage of cooling without the compressor. This requires either a) two physical thermostat wires for cooling, one for stage 1 and one for stage 2 cooling; or 2) one wire and an electronic device that allows multiplexing of two signals. For the buildings with only one wire for heating and one wire for cooling the technician can either pull a new thermostat wire or can add a multiplexer. These devices are available from several sources as shown below.

As illustrated below in Figure 41 the multiplexer has a Y-shaped piece (two diodes) that connect to the thermostat terminals, one diode to the first stage cooling and one to first stage heating. The diodes separate the 24 Volt AC current from the thermostat into either 24 Volt negative DC for heating or 24 Volt positive DC for cooling. (The second stage cooling then has its own wire). The rest of the multiplexing device then looks for either the negative or positive DC on the one wire and it sends a full 24 Volt AC to either the first stage heating or the first stage cooling (economizer).

The labor cost of pulling new wire is assumed to be about the same as buying and installing the multiplex device, about $145 parts and labor. The cost of the device alone is $30. Products are available from Robert Shaw, Carrier, Venstar, and ECCO.

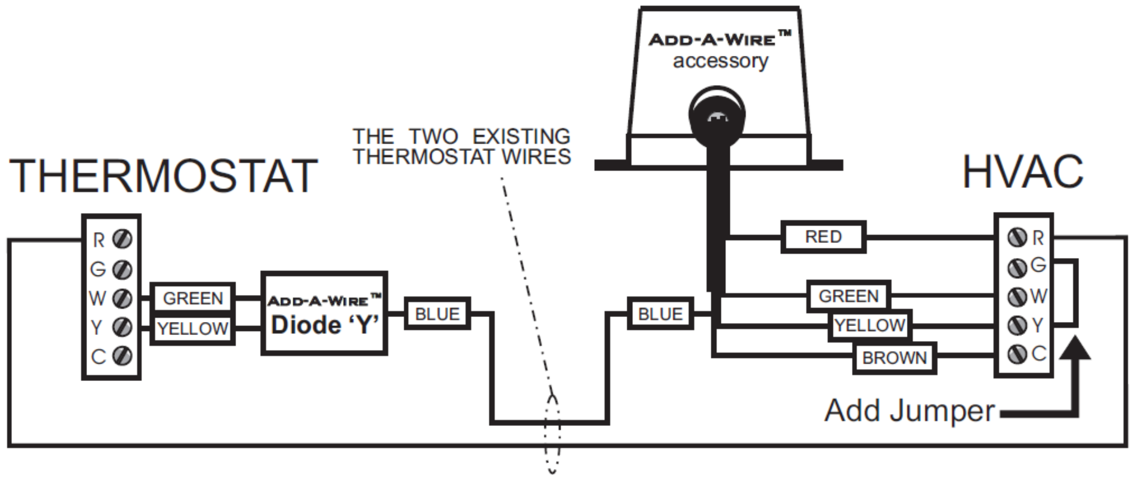


Figure 41 Multiplexer Schematic for Two-Stage Thermostat Retrofit

Energy simulation

See Appendix A: Prototype DOE-2 Model Descriptions for the energy simulation inputs.

Energy Savings

Detailed energy savings results are provided in Appendix D: Energy Savings for Two-Stage Thermostat. The Present Value (PV) energy savings over the effective useful life (EUL) of 15 years is $1,556 per zone. The first year energy savings is 1,110 kWh per zone. The first year and 15-year statewide savings realized by implementing this measure are presented in Figure 42.The statewide savings is calculated using the same methods detailed in the FDD Energy Savings section.

Statewide Savings	Electricity Savings (kWh)	TDV Total $
1st Year Savings	18,883,671	$2,223,404
15 Year Savings	278,107,385	$26,458,512

Figure 42 Two-Stage Thermostat Statewide Savings

Cost Effectiveness

No incremental maintenance costs are expected relative to the base case. As shown in Figure 43, this measure is cost effective.

Incremental Installed Cost	$122
Incremental Annual Maintenance	$0
Total Incremental Cost	$122
NPV of Energy Savings	$1,556
Lifecycle cost savings	$1,434
Benefit/Cost Ratio	12.8

Figure 43 Two-Stage Thermostat: Lifecycle Cost Results

Economizer Size Threshold

Currently, economizers are required on air conditioners with capacities greater than 75,000 Btu/hr. This proposal updates the requirements to cover units with capacities greater than 54,000 Btu/hr.

The analysis for the ASHRAE 90.1-2010 economizer addendum indicates economizers are cost effective down to at least 24,000 Btu/h in all the California climate zones except ASHRAE climate zone 2B (El Centro), which is cost effective down to 36,000 Btu/h. Dick Lord reports, "After review with the Mechanical subcommittee it was agreed to lower the threshold to 54,000 Btu/h which allows for the large 5 ton packaged unit volume to be included. For some of the zones we could go lower, but the use of the 54,000 harmonizes with several of the other standards and state codes. We will continue to evaluate extending it to lower numbers as part of some additional studies."[xxxv]

Using the ASHRAE methodology and California energy costs ($0.16/kWh) instead of ASHRAE energy costs ($0.09/kWh) results in cost effectiveness down to at least 24,000 Btu/h for all the California climate zones. This is summarized in Figure 44 below. Cost effectiveness is bounded by the scalar limit, which refers to the maximum allowable payback in years. Using the California LCC cost assumptions and energy costs, the scalar criteria is 11.9 years. In other words, this is the present worth multiplier for the measure lifetime of 15 years. In all the climate zones the calculated scalar is less than the limit, which means the measure is cost effective. For example, this measure has a simple payback of 6.0 years in CTZ 2b, which pays back sooner than the limit of 11.9 years.

ASHRAE CTZ in CA	CA CTZ	CA Scalar (years)
2b	15	6.0
3b	7-14	3.4
3c	2-6	2.0
4b	16	2.3
4c	1	3.5
5b	16	3.2
6b	16	2.9

Figure 44 Economizer Analysis using ASHRAE Methodology for 24 kBtu/h

Reducing the size at which economizers are required will result in significant energy savings statewide, as 60% of the total installed DX cooling capacity in California new construction is systems 10 tons and smaller as shown in the following histogram in Figure 45. In terms of units sold, the most popular size is 5 tons, which is below the current requirement threshold of 6.25 tons. These data are presented in fractions of total installed tonnage.

Figure 45 Unitary System Market Share by Cooling Capacity, California

More recent market data provided by Carrier for the year 2010 shows a slightly different distribution. These data are presented by total annual sales in each tonnage grouping for California. In this case 3-ton units compose the leading market share while 5-ton units are a close second. This is illustrated in Figure 46.

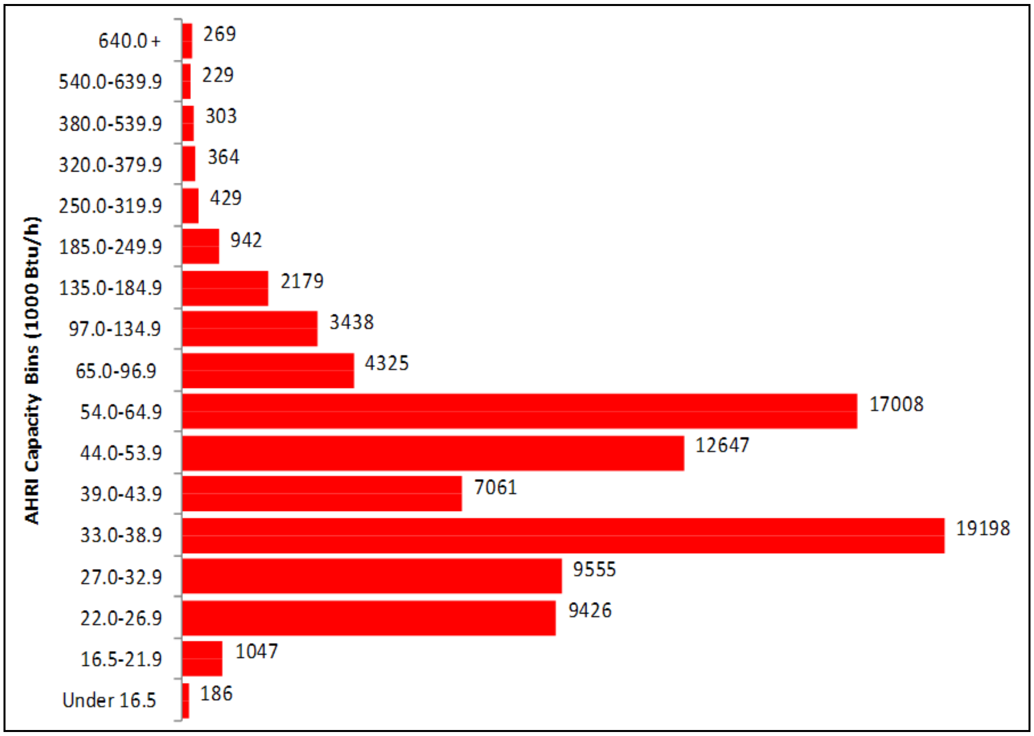


Figure 46 Unitary System Market Share by Cooling Capacity, California 2010

Energy simulation

See Appendix A: Prototype DOE-2 Model Descriptions for the energy simulation inputs.

Energy Savings

Time dependent valuation (TDV) multipliers were applied to the hourly outputs from the DOE-2 models to estimate the energy consumption and costs on a TDV basis. The Present Value (PV) energy savings over the effective useful life (EUL) of 15 years is $263 per ton. The first year electricity savings is 165 kWh per ton.

Detailed energy savings results are provided in Appendix E: Energy Savings for Economizer Size. The first year and 15-year statewide savings realized by implementing this measure are presented in Figure 47. The statewide savings is calculated using the same methods detailed in the FDD Energy Savings section.

Statewide Savings	Electricity Savings (kWh)	TDV Total $
1st Year Savings	29,094,731	$3,910,383
15 Year Savings	433,410,855	$46,533,561

Figure 47 Lower Economizer Threshold Statewide Savings

Measure Cost

The incremental costs of economizers are shown below in Figure 48. This is the final cost to the consumer. For conservativeness, the highest cost per size is selected for use in the cost effectiveness analysis, which is $786.

Btu/h	Tons	Mfg A Factory installed	Mfg A Field installed	Mfg B Factory installed	Mfg B Field installed	Mfg C Factory installed	Mfg D Factory installed	Mfg D Field installed	Max	Max $/ton
36,000	3.0	$422	$506	$785	$786	$750	$403	$486	$786	$262
48,000	4.0	$422	$506	$785	$786	$750	$403	$486	$786	$197
60,000	5.0	$422	$506	$785	$786	$750	$403	$486	$786	$157
72,000	6.0	$565	$580	$785	$786	$750	$403	$486	$786	$131
120,000	10.0	$565	$580	$804	$884	$850	$403	$486	$884	$88

Figure 48 Economizer Incremental Cost

Cost Effectiveness

Worst case the maintenance cost is $786 to replace the economizer. The economizer fault incidence over the 15 yr EUL is 48% per the AirCare Plus program dataset. $786 x 48% = $377. Assume this occurs half way through the 15 yrs, so the PV at year 7 is $307. This measure is cost effective for a 50,000 Btu/h RTU. The proposed value is 54,000 to match the ASHRAE 90.1-2010 threshold and it is exactly in between the nominal sizes of 48,000 and 60,000 Btu/h so as to avoid confusion which size units this applies to. The lifecycle cost results are shown in Figure 49 for a 54,000 Btu/h unit. The cost per ton decreases with increasing capacity, while the savings per ton is constant. Thus, all larger units are also cost effective.

Incremental Installed Cost	$786
NPV of Maintenance	$307
Total Incremental Cost	$1,093
NPV of Energy Savings	$1,182
Lifecycle cost savings	$89
Benefit/Cost Ratio	1.1

Figure 49 Lower Economizer Threshold: Lifecycle Cost Results, 54 kBtu/h RTU

Economizer Damper Leakage

The ASHRAE 90.1 mechanical subcommittee investigated this measure and shared their analysis with us, which is used extensively for this proposal and described here. "The damper leakage for outside air dampers is only an issue on units when they are running in the unoccupied mode for heating or cooling. That means it is not an issue on a 24/7 operation and is only an issue in the buildings that have unoccupied heating and cooling. In the occupied mode the dampers are open for minimum ventilation air so leakage is a non-issue. In the unoccupied mode the leakage is only an issue when the fan is on for heating or cooling, but the fan is cycled in most applications so when the fan is off there is no leakage."[xxxvi]

The ASHRAE 90.1 committee's methodology is outlined here:

- Used the small office building spreadsheet model to calculate the energy loss or gain
- Only considered the unoccupied hours when the fan was running.
- Calculated the additional heating and cooling load by taking the leakage air times the difference in enthalpy between the run air and outside air.
- Used the leakage per ASHRAE 90.1 damper leakage table with 4 cfm/sf for ASHRAE climate zones 1, 2, 6, 7, and 8 (Eastern Sierra south of Lake Tahoe). Used 10 cfm/sf for all other zones (most of California).
- From some testing that Carrier did, used a damper leakage of 25 cfm/sf for the typical product (base case). Also doubled this value to 50 cfm/sf to investigate the impact.
- Included leakage through the outside air damper and exhaust damper. Outside air damper size was calculated based on a 400 fpm face velocity and exhaust on 600 ft/min.
- Corrected the leakage to 0.5 inch static as the ratings are based on the AMCA Standard 500, which is at 1 inch of static. (0.5/1.0)^0.5=0.71.

Energy Savings

This measure has insignificant energy savings as discussed in the Cost Effectiveness section.

Measure Cost

ASHRAE methodology used typical industry cost of $10/sf to make a low leak damper.

Cost Effectiveness

This proposal directly relies on the ASHRAE analysis and results, but slightly revised to account for California energy costs and scalar. The ASHRAE cost effectiveness analysis used $0.09/kWh with a scalar of 8.8 (maximum allowable simple payback in years). The California 2013 cost effectiveness analysis uses $0.16/kWh with a scalar of 11.9 years.

The results of the ASHRAE 90.1 committee's analysis are outlined here and presented in Figure 50.

ASHRAE CTZ in CA	CA CTZ	CA Scalar (years)
2b	15	244
3b	7-14	282,075
3c	2-6	44,737
4b	16	726
4c	1	never
5b	16	3,111
6b	16	2

Figure 50 Damper Leakage Analysis using ASHRAE Methodology for 10 cfm/sf

- It looks very questionable to justify the values in the damper leakage table for the California climate zones.
- We can justify the values for a small portion of California climate zone 16, however this is the sparsely populated Eastern Sierra south of Lake Tahoe.
- The results do not change even when doubling the base case leakage from 25 to 50 cfm/ft2
- The study is highly dependent on the hours of unoccupied operation, which is strongly tied to setback temperatures.
- ASHRAE 90.1 adopted these requirements knowing that it can not be fully justified

Using this ASHRAE analysis with these California parameters yields the result that damper leakage lower than 10 cfm/sf is not cost justified in California. Thus, this proposal will set the statewide maximum damper leakage at 10 cfm/sf at 1.0 in w.g., which would harmonize with ASHRAE 90.1.

Economizer Reliability

This proposal includes mandatory performance features for economizers and revising the current option for RTU manufacturers to apply to the CEC for a certification for a factory installed and calibrated economizer. For certified equipment, the economizer is exempted from the functional testing requirement (but not the construction inspection requirement) as described in Standards Appendix NA7.5.4 “Air Economizer Controls” and on the MECH-5 acceptance testing form.

The proposed "Manufacturer Certification to the California Energy Commission for Factory Installed and Calibrated Economizers" is included in Appendix G: Manufacturer Certification to the California Energy Commission for Factory Installed and Calibrated Economizers. The elements of the economizer certification per each make/model and also for each individual unit are presented in this appendix.

The corresponding Sample Certificate Factory Installed and Calibrated Economizers is included in Appendix H: Sample Certificate Factory Installed and Calibrated Economizers.

Appendix I: Economizer Inspection and Functional Testing contains a table that summarizes the inspection activities and functional testing associated with:

- Certification for a factory installed and calibrated economizer
- Current 2008 MECH-5A (Air Economizer Controls acceptance test)
- 2013 MECH-5A for field-installed economizers
- 2013 MECH-5A for factory installed and certified economizers.

Based on the data analysis, the AirCare Plus program database shows a correlation that indicates broken economizers are more common on units where the economizer was installed in the field as opposed to factory-installed, as indicated in Figure 51. This measure will encourage more factory installation instead of field installation of economizers because it allows an option for reduced cost for compliance. RTU manufacturers can apply to the CEC for a certification for a factory installed and calibrated economizer. This is a one time process for each RTU model. For certified equipment, the economizer is exempted from the functional testing requirements in the Air Economizer Controls acceptance test.

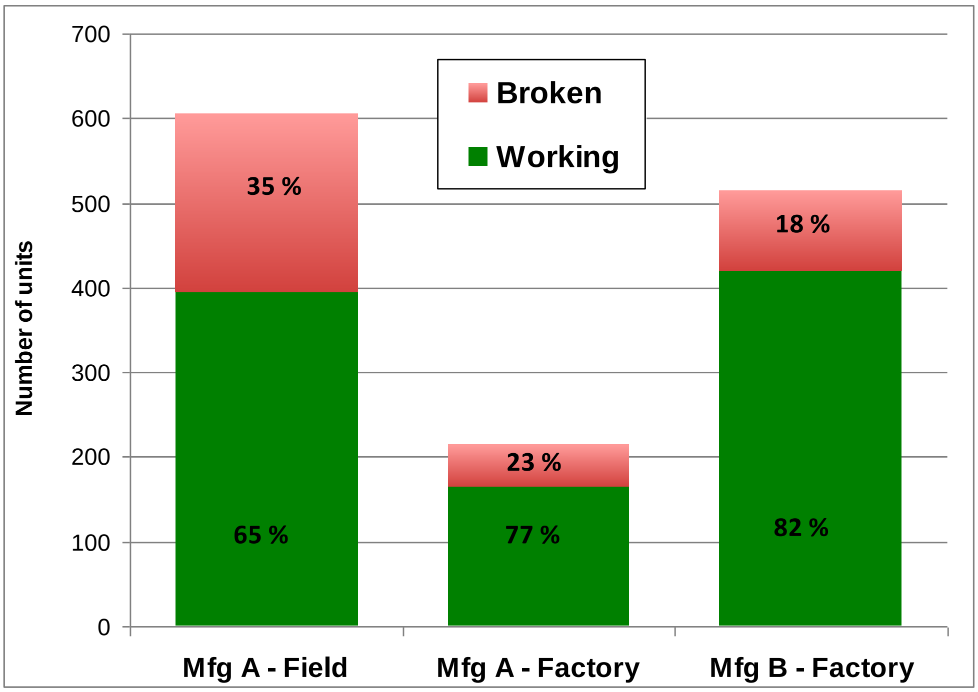


Figure 51 Reliability of Factory- and Field-Installed Economizers

The project team contacted a number of stakeholders to discuss this proposal and learned:

- RTUs larger than 25 tons usually have a factory-installed economizer
- RTUs smaller than 25 tons usually have a field-installed economizer
- Per written comments by AHRI, "Larger units above 15 tons are usually factory installed."
- The industry is dominated by three economizer manufacturers: MicroMetl, Ruskin Rooftop Systems, and CanFab

Through additional communication with stakeholders we learned that typical installation practice for field-installed economizers includes the following tasks:

- Installation time is less than 20 minutes

- The minimum ventilation position is established using the rule of thumb: position the dampers a thumb's width apart
- Set the high-limit setting on the economizer controller
- Configure the CO2 sensor if the unit is equipped with demand controlled ventilation (DCV)
- Performance verification is uncommon

Energy Savings

The energy savings analysis is a spreadsheet based calculation that relies on the energy simulations performed for the FDD measure. This proposal would primarily affect the following three failure modes: incorrect economizer high-limit setpoint, economizer stuck open, and economizer stuck closed. Figure 53 shows the TDV savings for these three failure modes from the energy simulations performed for the FDD measure. These savings are multiplied by the fault incidence as derived and explained in the section Probability Analysis. The total TDV savings for this measure is $905/ton. For a system with 45,000 Btu/h cooling capacity, the PV savings is thus $3,394. These results are in very close agreement with the savings reported by the Advanced Rooftop Unit (ARTU) PIER project.[xxxvii] This project reports savings of $270 to $500 (average $385) for a 5-ton unit with similar features categorized in the Operational Performance and Reliability and Robustness sections of the project report. The ARTU savings is thus $919/ton over 11.94 years, which is close to the $905/ton savings used in this analysis.

Fault	Fault incidence	TDV Savings per ton	Incid x Save per ton
Economizer high-limit setpoint incorrect	30%	$770	$231
Economizer stuck closed	24%	$903	$217
Economizer stuck open	24%	$1,905	$457
Total			**$905**

Figure 52 Summary of savings for economizer reliability proposal

Measure Cost

The measure cost analysis relies on the findings of the Advanced Rooftop Unit (ARTU) PIER project. The incremental measure cost is $3,202. This is derived from the ARTU conclusion that the incremental measure cost is $4,100. Subtracting the $425 average cost for the Diagnostics and Monitoring feature set, which is not included in the list of proposed performance criteria, yields an incremental measure cost of $3,675. The ARTU incremental cost also includes the incremental cost between 13 SEER and 14 SEER. The incremental cost of this additional SEER value is $437. This is from a cost analysis performed by the DOE,[xxxviii] then escalated to 2013 dollars by 3% per year. Subtracting the $473 incremental cost yields an incremental measure cost of $3,202. This is a conservative (high) estimate because the ARTU feature set includes 26 features in the Operational Performance and the Reliability and Robustness feature groups, while this proposal includes only a subset of 10 of these 26 features.

Cost Effectiveness

No incremental maintenance costs are expected relative to the base case. As shown in Figure 53, this measure is cost effective for a 45,000 Btu/h RTU. The cost per ton decreases with increasing capacity, while the savings per ton is constant. Thus, all larger units are also cost effective.

Incremental Installed Cost	$ 3,202
Incremental Annual Maintenance	$0
Total Incremental Cost	$3,202
NPV of Energy Savings	$3,394
Lifecycle cost savings	$192
Benefit/Cost Ratio	1.06

Figure 53 Economizer Reliability: Lifecycle Cost Results, 45 kBtu/h RTU

High Limit Switch Performance

This section presents a description of the Analysis, the results, and our conclusions and recommendations.

Economizer High Limit Analysis

Outdoor air economizers use controllable dampers to increase the amount of outside air drawn into the building when the outside air is cool or cold and the system requires cooling. A typical design is shown in Figure 54. Supply air temperature is maintained at setpoint by first opening the economizer outdoor air damper and closing the return air damper, then opening the chilled water valve if additional cooling is required. A key element of the economizer control system is the high limit switch that determines whether outdoor air is in fact appropriate for cooling and enables or disables the economizer dampers accordingly. This high limit device, which has long been misunderstood, is the subject of this analysis.

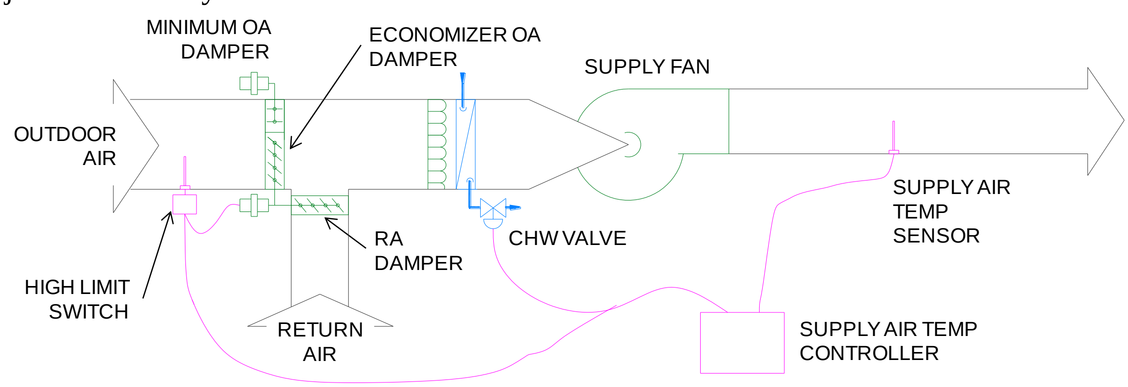


Figure 54 Outdoor Air Economizer Controls

The purpose of the high limit switch is to disable the economizer when its use would increase the energy used by the cooling coil, i.e. when cooling return air will use less mechanical cooling energy than cooling outdoor air. Determining when the changeover condition occurs is complicated by the fact that cooling coils both cool and dehumidify supply air.

Figure 55 is a psychrometric chart showing entering coil conditions that have a higher dewpoint temperature than the desired supply air temperature and thus the air is dehumidified (wet coil). Coil cooling energy is proportional to the enthalpy difference across the coil from the entering condition to the supply air condition. The return air condition in this example is 76°F drybulb temperature with a humidity ratio of 68 grains (1 grain = 7000 lbw/lb$_{da}$). If the outdoor air were 78°F and 60 grains (outdoor air condition #2, green dot), the enthalpy difference across the coil would be less than that required to cool return air to the supply air temperature despite the fact that the drybulb temperature is higher than the return air drybulb temperature. This is because the outdoor air results in a lower latent cooling load. Conversely, if the outdoor air were 74°F and 92 grains (outdoor air condition #1, red dot), it would take more energy to cool than the return air despite having a lower drybulb temperature, due to the higher latent load component. So with a wet coil (if the return air has a higher dewpoint temperature than the supply air temperature setpoint, assuming near saturated conditions leaving the coil as is typical of a wet coil), the optimum economizer high limit logic is to cool the airstream that has the lower enthalpy.

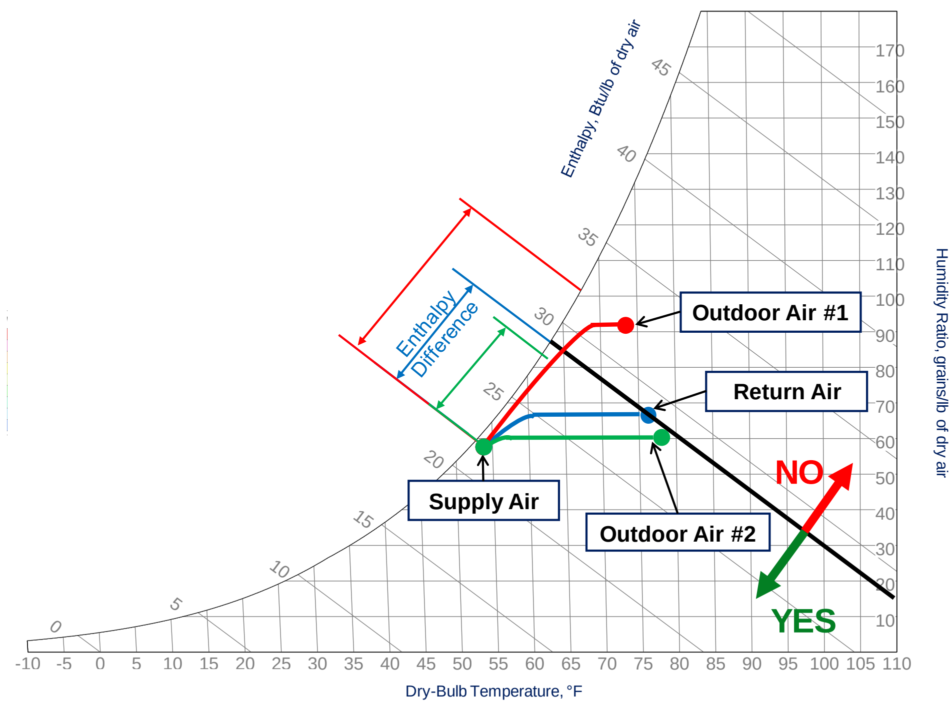


Figure 55. Optimum High Limit Logic – Wet Coil

The physics of a dry coil is quite different. In Figure 56, entering coil dewpoint temperatures are below the supply air temperature dewpoint so no dehumidification occurs. The energy usage across the coil is still proportional to the enthalpy difference but the leaving air is no longer near saturation – the humidity ratio is the same as the entering airstream. With a dry coil, cooling outdoor air from 81°F and 46 grains takes more energy than cooling the return air despite a lower enthalpy. So optimum dry coil logic is to cool the airstream that has the lowest drybulb temperature regardless of humidity.

These two figures are combined in

Figure 57. Interestingly, very seldom is this combined wet/dry (enthalpy/drybulb) logic recognized as being optimum. For instance, ASHRAE's new green building Standard 189.1[xxxix] has requirements for enthalpy and drybulb high limit devices, but no requirement for combined enthalpy and drybulb high limit logic.

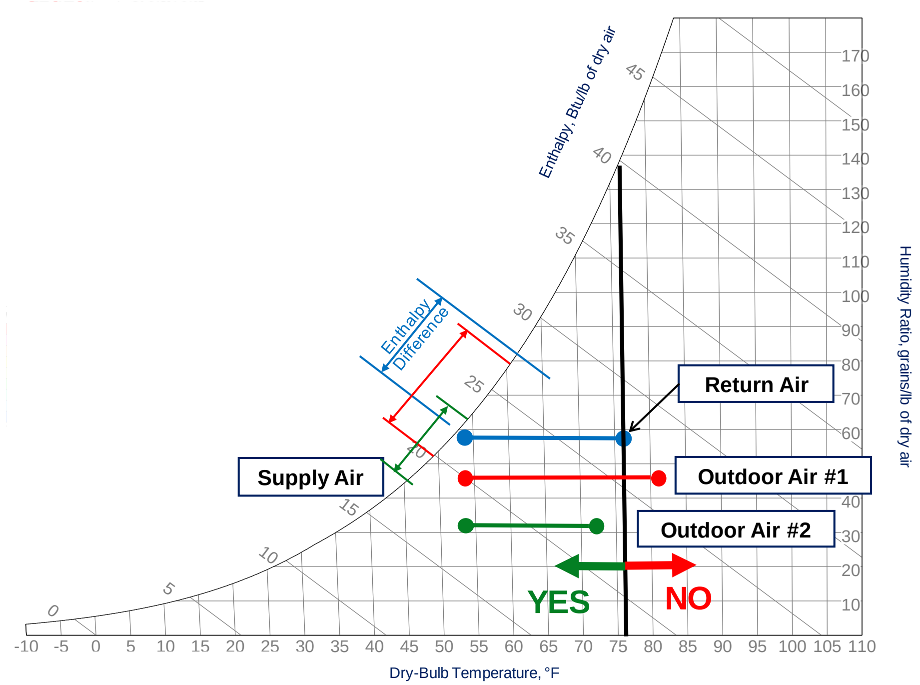


Figure 56. Optimum High Limit Logic – Dry Coil

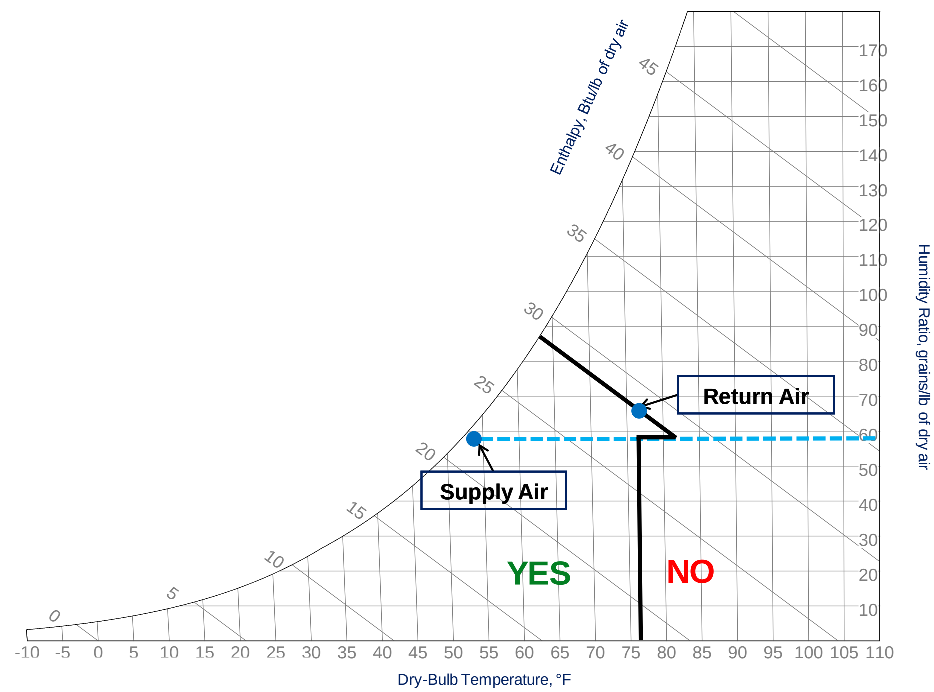


Figure 57. Optimum High Limit Logic – Wet or Dry Coil

In these figures and in the discussion below, it is assumed that the economizer is fully "integrated," meaning the economizer and mechanical cooling can operate simultaneously. This is always true of chilled water systems and those direct expansion (DX) systems with modulating or several stages of capacity control, but it is generally not the case for small DX units with limiting unloading capability. The optimum economizer high limit control from an energy perspective is the same for integrated or

partially integrated DX equipment. In very humid climates, economizer control for some applications may have an impact on space humidity that results from compressor cycling, however, this cannot currently be accurately modeled in any software and is not expected to be a concern in the California climate zones. The results and recommendations discussed below may not apply to these non-integrated economizers. It should be noted that for fully integrated economizers, the selection of high limit control will not cause any increase in humidity in humid weather. A typical misperception among the design community is that enthalpy economizer control (as opposed to only drybulb control) is required in humid climates in order to control interior space humidity. Fundamental review of the psychrometrics shows otherwise; this can be seen in
Figure 55: the supply air condition is the same regardless of entering air condition, and it is the supply air condition that determines the room humidity.

The most common high limit controls are:

1. Fixed drybulb temperature
2. Differential (or dual) drybulb temperature
3. Fixed enthalpy
4. Differential (or dual) enthalpy
5. Combinations of the above

Each of these controls has inherent errors – conditions where they make the wrong choice between the outdoor air and return air airstreams causing an increase in energy usage compared to the ideal logic (

Figure 57), and these errors increase in practice due to sensor calibration. These issues are discussed in more detail for each high limit control below.

Fixed Drybulb Temperature

With a fixed drybulb high limit, outside air temperature is measured and compared to a fixed setpoint, enabling the economizer if the outdoor air temperature is below the setpoint. This was the first and remains the simplest and least expensive high limit control, requiring only a single temperature sensor or thermostat mounted in the outdoor airstream.

Figure 58 is a psychrometric chart showing fixed drybulb control with setpoint equal to 72°F superimposed over ideal control. The shaded areas represent outside air conditions where the control strategy makes an error by incorrectly selecting the more energy intensive airstream. In this example, the return air is 76°F and 68 grains (the return air condition, of course, is a not a constant). In the upper red triangle, the control incorrectly supplies humid outdoor air. In the lower red rectangle, the control incorrectly disables the economizer when outdoor air would have reduced coil load.

Figure 59 is the same chart with a setpoint of 65°F. This setpoint reduces the number of hours the control incorrectly supplies humid air (upper triangle) but it increases the number of hours when the economizer incorrectly is disabled in dry weather. In some humid climates, those with many hours in the upper triangle and fewer hours in the lower rectangle, this lower setpoint will improve efficiency. This will be seen in the energy simulations discussed below.

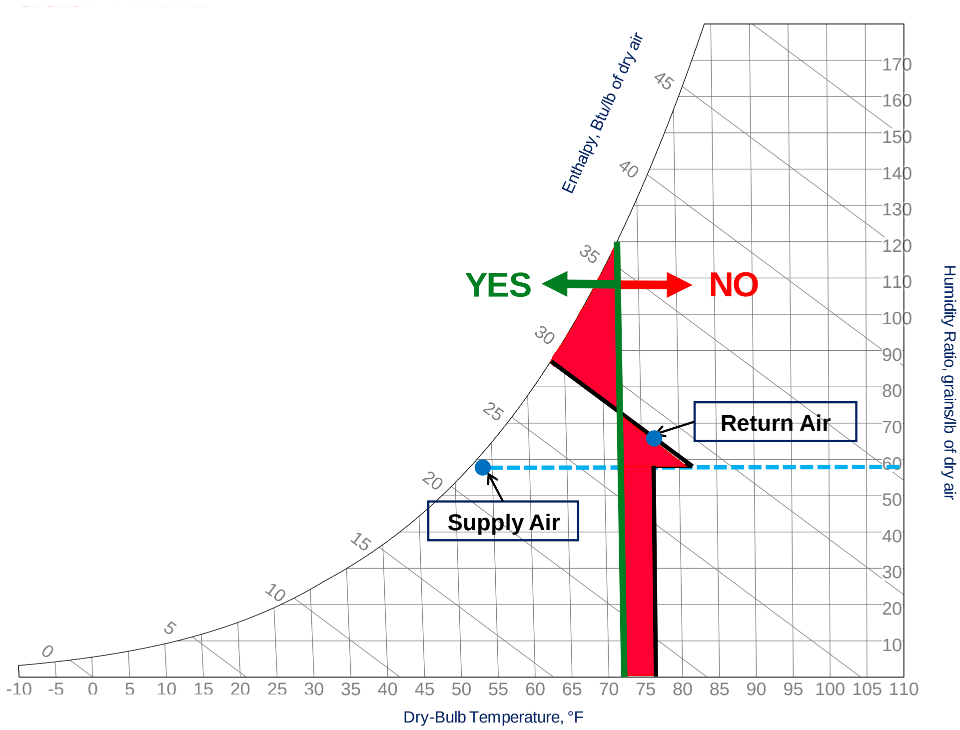


Figure 58. Fixed Drybulb High Limit Error – 72°F Setpoint

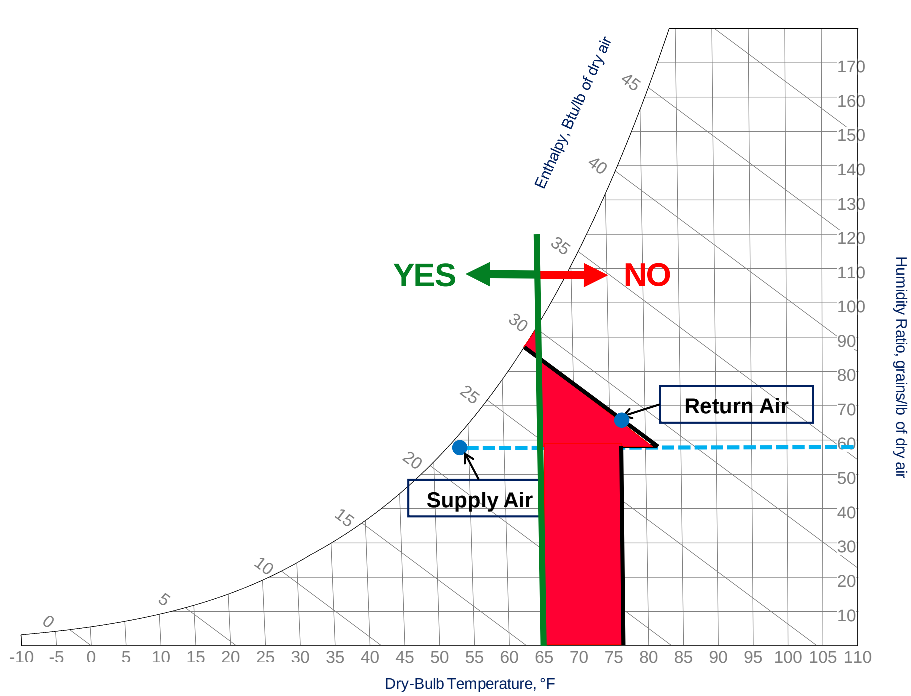


Figure 59. Fixed Drybulb High Limit Error – 65°F Setpoint

Differential Drybulb Temperature

With a differential drybulb high limit, both outside air and return air temperatures are measured and the economizer is disabled when the outside air temperature exceeds the return air temperature. This control logic will always make the right choice (barring sensor error) between airstreams when the coil is dry (

Figure 60), but also always makes an error when outdoor air is cool but humid (upper triangle). The impact of this error depends on the climate. It will have almost no effect in San Francisco (

Figure 61) since there are very few hours with the outdoor air conditions in this error triangle. But the error will be significant in San Diego (Figure 62) where there are many hours in this error triangle. In these figures, the annual number of hours between 6AM and 6PM at each psychrometric condition is indicated by a colored square indicating the frequency as indicated in the scale on the left.

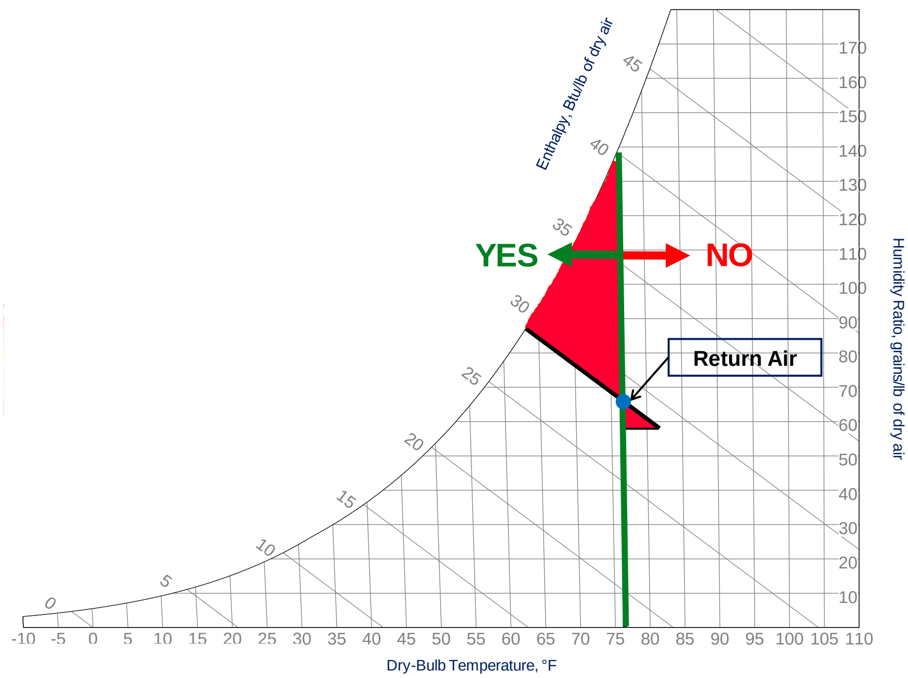


Figure 60. Differential Drybulb High Limit Error

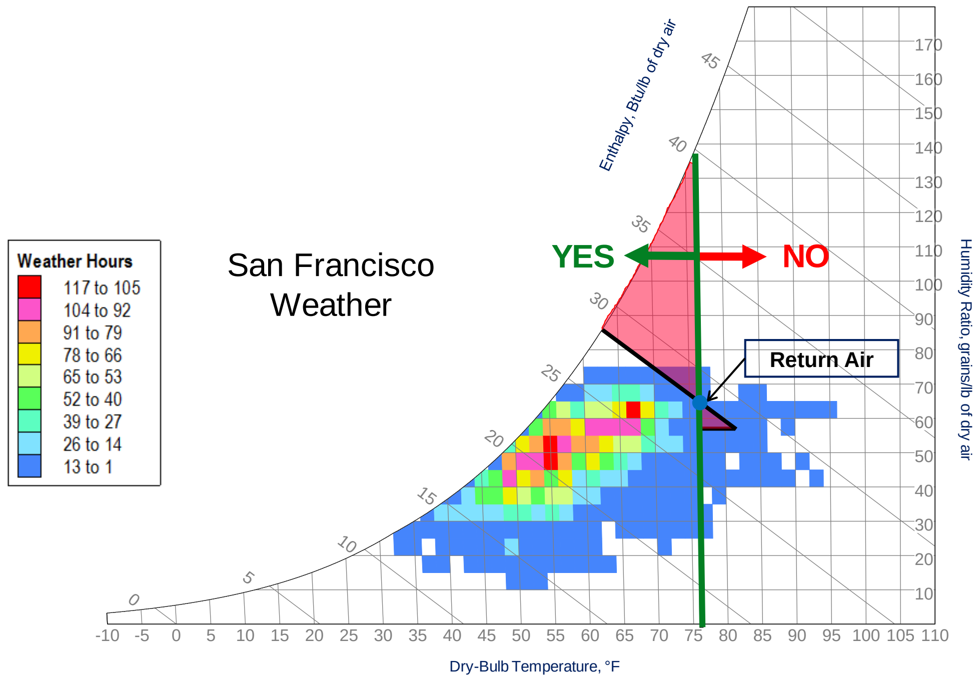


Figure 61. Differential Drybulb High Limit Error – San Francisco Weather

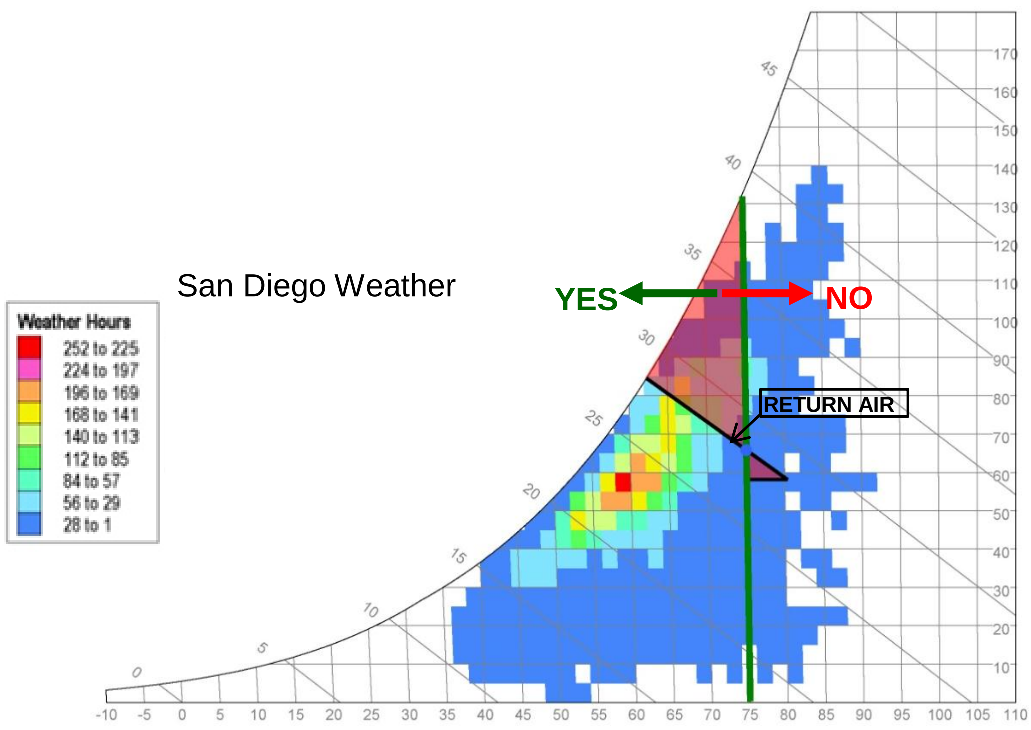


Figure 62. Differential Drybulb High Limit Error – San Diego Weather

Fixed Enthalpy

Fixed enthalpy high limit controls measure outside air enthalpy and compare it to a fixed setpoint, typically equal to the expected enthalpy of the return air (e.g. 28 Btu/lb_{da}), disabling the economizer if the outdoor air enthalpy is above the setpoint. Typically, for digital control systems, enthalpy is calculated from two sensors, a temperature sensor and a relative humidity sensor. Enthalpy can also be measured with a dedicated enthalpy sensor, but this is actually the same two sensors built into a single housing with the enthalpy output signal calculated electronically from temperature and humidity. Since knowing temperature and humidity separately is usually desirable, most digital control systems use separate sensors.

Fixed enthalpy logic has two errors, a small error caused when the setpoint is above or below the actual return air condition (the red rectangle parallel to the enthalpy lines) and a large error when the coil is dry (lower red trapezoid). The former error seldom has a significant impact on energy performance despite the fact that return air conditions will vary year round. This is because the setpoint only has to be near the actual return air enthalpy when the economizer needs to be turned off, i.e. when outdoor air conditions are hot or humid, and the return air enthalpy tends to be consistently around 28 Btu/lb_{da} under those conditions. The impact of the dry-coil error varies with climate. If the weather is dry like in Palmdale, the energy impact can be significant. If the weather is more humid like San Diego, the impact is very small.

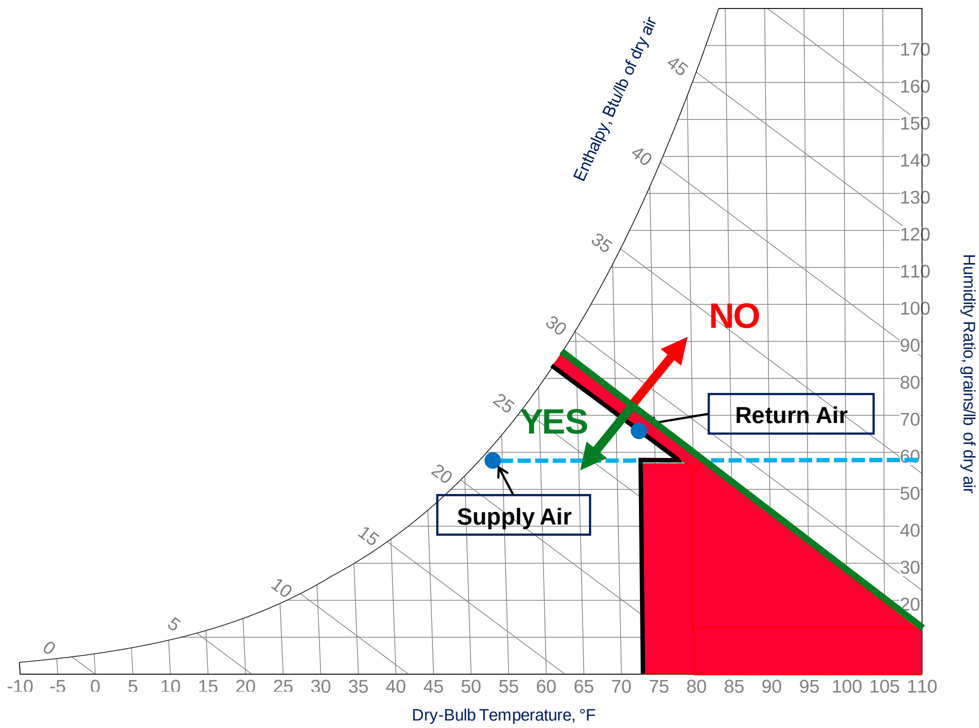


Figure 63. Fixed Enthalpy High Limit Error

Differential Enthalpy

Differential enthalpy high limit controls measure the enthalpy of both the outside air and return air streams and disable the economizer when the outside air enthalpy exceeds that of the return air. Because this control requires four sensors (temperature and relative humidity of outdoor air plus temperature and relative humidity of the return air) it is the most expensive and most prone to sensor error. Contrary to common knowledge (and to green building standards like Standard 189.1), differential enthalpy is not the most efficient high limit logic, even theoretically as can be seen by Figure 64. The control logic will be in error when the coil is dry and outdoor air is warm and dry.

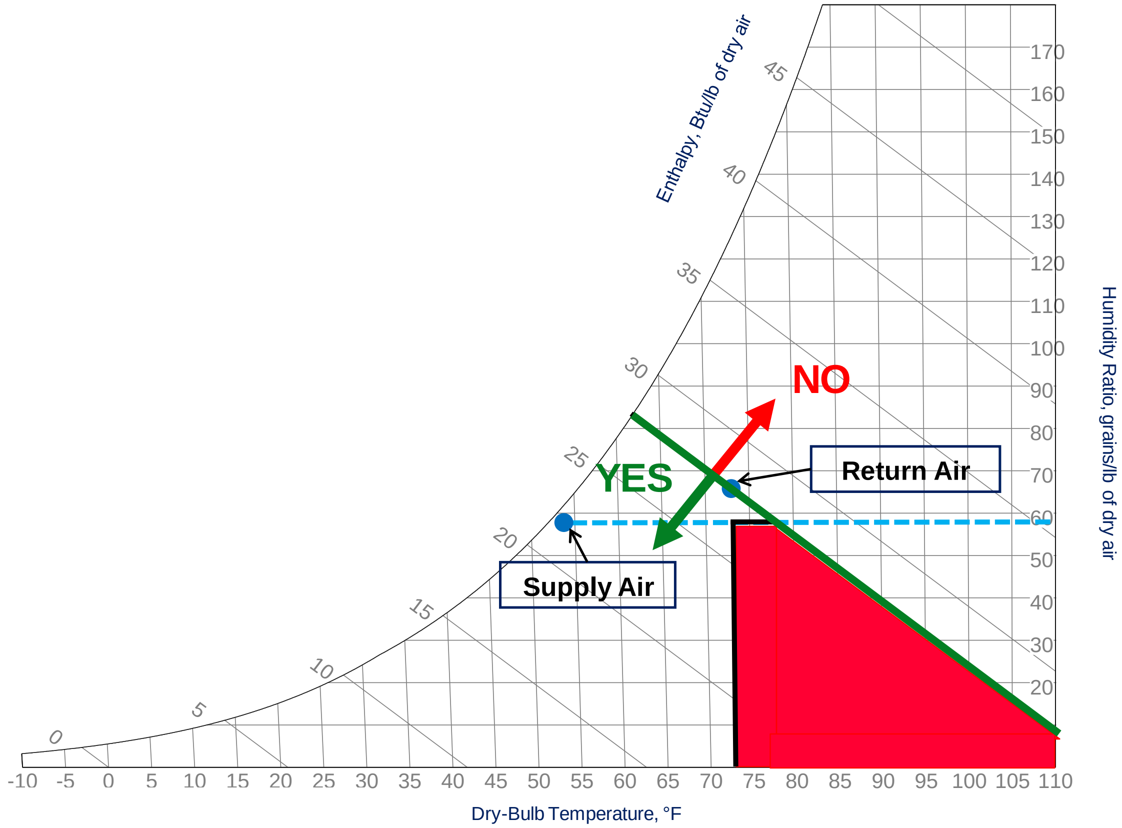


Figure 64. Differential Enthalpy High Limit Error

Combination High Limits

From

Figure 57, it is clear that combinations of the drybulb and enthalpy high limit controls can be the most efficient.

Figure 65 shows that combination differential drybulb and differential enthalpy high limit will have almost no theoretical error. A combination fixed drybulb and fixed enthalpy high limit will be almost as effective, with small added errors when actual return air drybulb and enthalpy differ from the respective setpoints (

Figure 66). Since the fixed enthalpy logic ensures humid cool air is not selected, the drybulb setpoint should be set for the expected return air temperature (e.g. 75°F) regardless of climate, not adjusted downward as in

Figure 59.

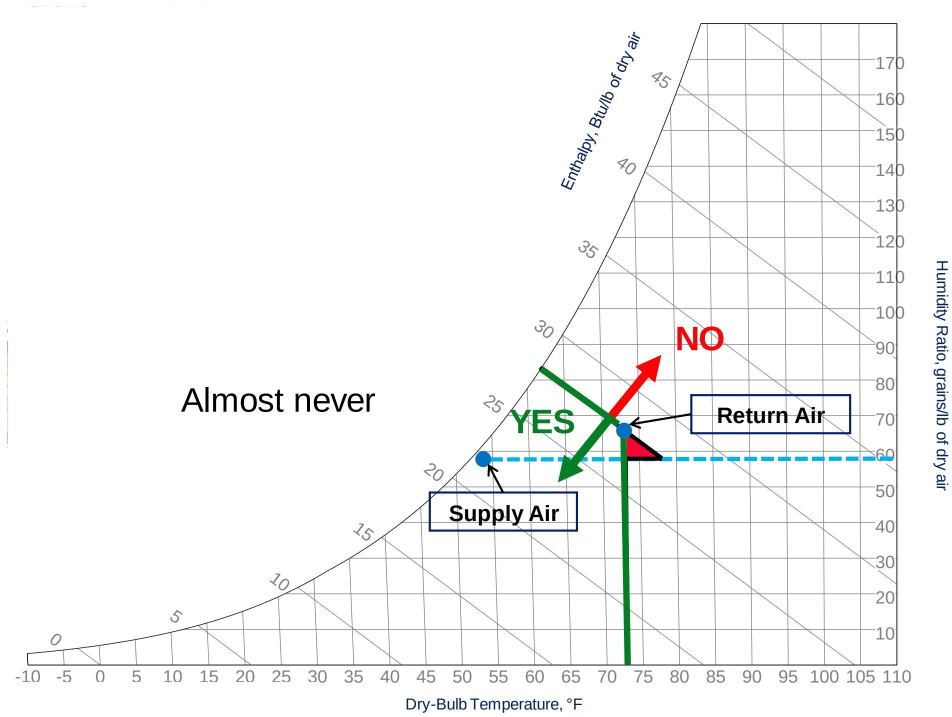


Figure 65. Error for a Combination High Limit of Differential Drybulb and Differential Enthalpy

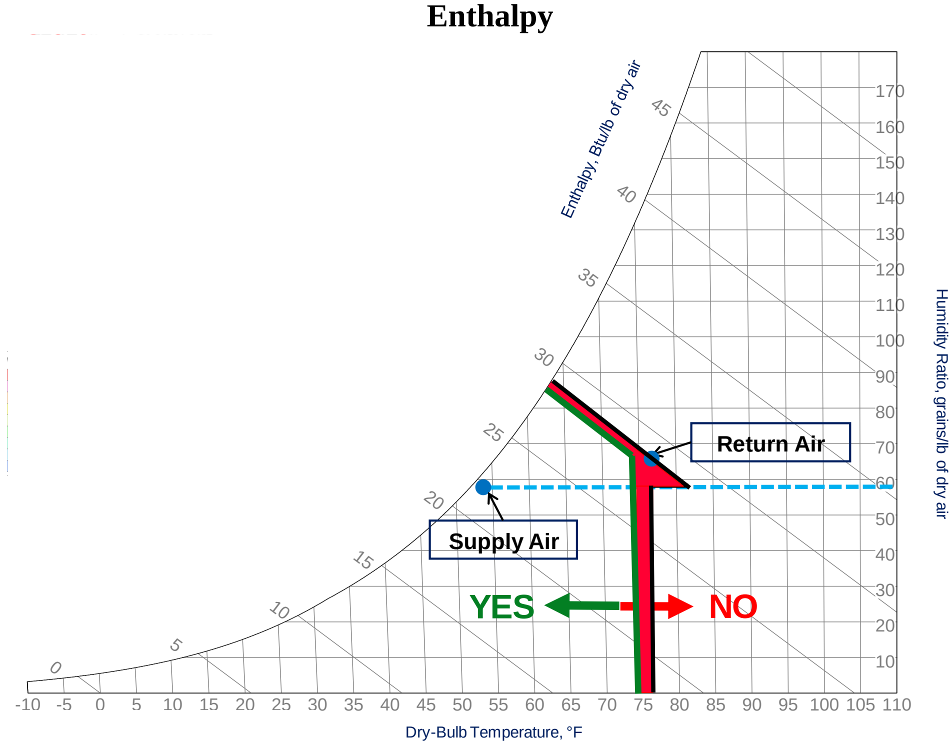


Figure 66. Error for a Combination High Limit of Fixed Drybulb and Fixed Enthalpy

A special type of combination high limit switch is what Title 24 refers to as an "electronic enthalpy" high limit. This very clever electronic controller has been used for many years with packaged AC units with electric or electronic controls. It originally used hygroscopic materials such as nylon for humidity sensing, but now is entirely solid state and thus much more reliable. Its setpoints (“A” through “D”) form a curve on the psychrometric chart (

Figure 67). When set to setpoint “A” (a requirement of Title 24 regardless of climate), it mimics a combination of a fixed enthalpy control with a setpoint of 27 Btu/lb_{da} and a fixed drybulb control with a setpoint of 73°F. The control error is relatively small, as shown in Figure 68.

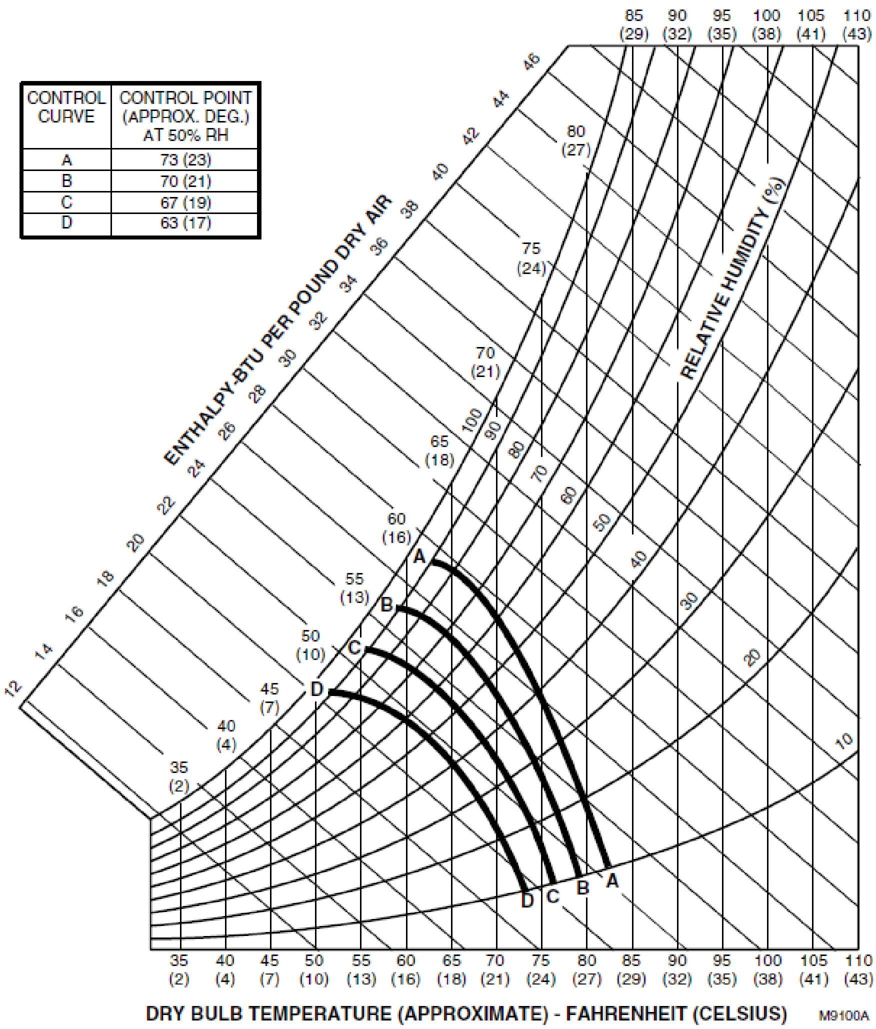


Figure 67. Electronic Enthalpy Controller

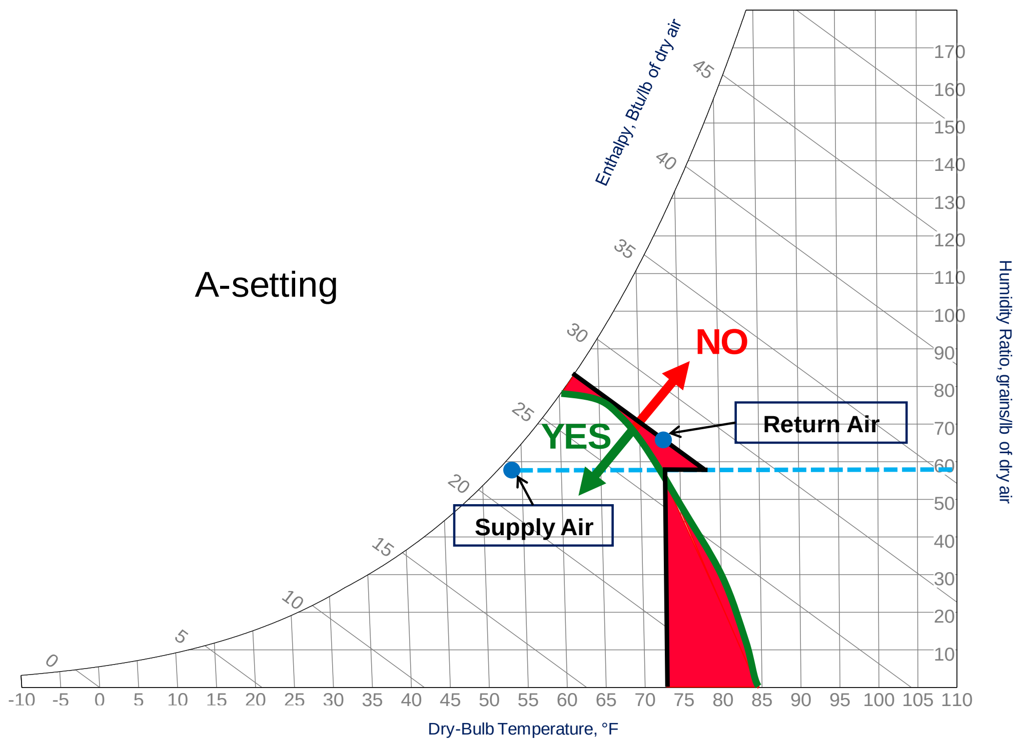


Figure 68. Electronic Enthalpy Controller Error – "A" Setting

Sensor Error

The figures above all assume perfect sensors with 0% error. Real sensors will of course have accuracy and repeatability limitations depending on the type and quality of the sensor. In HVAC applications, temperature is most commonly measured using thermistors or resistance temperature detectors (RTDs). Thermistors are now the most common sensor and are typically ±0.35°F, although extra precision thermistors are available with about half that error. Humidity is most commonly measured using capacitive or resistive relative humidity sensors offered in three accuracy ranges, ±1%, ±3%, and ±5% with ±3% being the most common for HVAC applications.

These are manufacturer listed accuracies. Actual accuracy will vary depending on the quality of the sensor and how well and how frequently the sensor has been calibrated. Temperature sensors tend to be very stable and remain accurate for many years[xl, xli]. Humidity sensors, on the other hand, are notorious for being difficult to maintain in calibration. A recent test of commercial humidity sensors[xlii ,xliii] showed that few of the sensors met manufacturer's claimed accuracy levels out of the box and were even worse in real applications. **Error! Reference source not found.** and **Error! Reference source not found.** show the results of the NBCIP one year in situ tests of two brands of humidity sensors among the six brands tested. There were two sensors tested for each brand, represented by the orange and gray dots.

Figure 68 shows the best sensor in the study; both sensors were reasonably consistent and accurate, although even these top quality sensors did not meet the manufacturer's claim of ±3% accuracy. Figure 70 shows the worst sensor tested; both sensors generated almost random humidity readings.

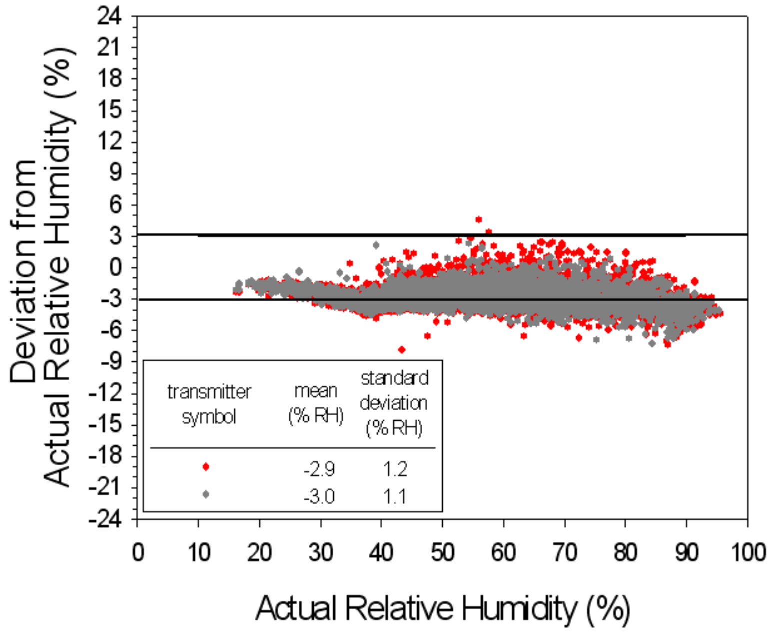


Figure 69 Iowa Energy Center NBCIP Study – Best Humidity Sensor

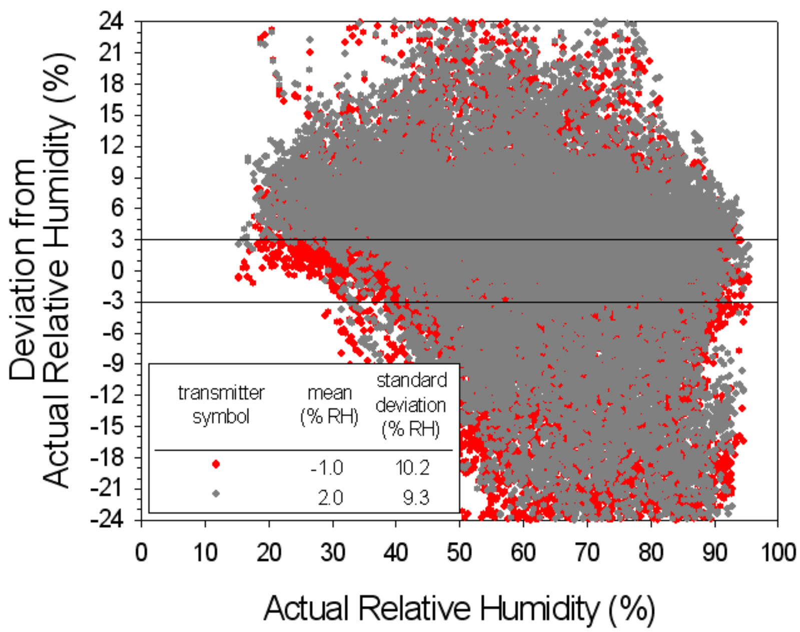


Figure 70 Iowa Energy Center NBCIP Study – One of the Worst Humidity Sensors

Results

Results are shown in Figure 71 through Figure 75 for all of the Title 24 climate zones. The y-axis is annual savings vs. no economizer in Wh/sf/year. Each column in the chart shows the performance of the high limit control with no sensor error. Each column also has an error bar which shows how the control would work if sensors had the errors listed in Table 2. The error bar in most cases is broken into two parts, one if the sensor error was high and one if the error was low. Strategies that result in significantly increased energy use (negative savings) may extend off the charts.

Figure 76 shows the maximum combined error required of a dual enthalpy control to have the same energy performance of a simple fixed drybulb switch with ±2°F error. The roughly equivalent humidity error, assuming zero drybulb sensor error, is shown on the right. In most cases two humidity sensors with ±1% accuracy would not be accurate enough, again assuming no drybulb error. This figure demonstrates that it will be almost impossible for sensors to be accurate enough for dual enthalpy control to beat a simple drybulb switch, and certainly impossible for dual enthalpy control to be life cycle cost effective vs. a drybulb switch given the significant added first costs and maintenance costs.

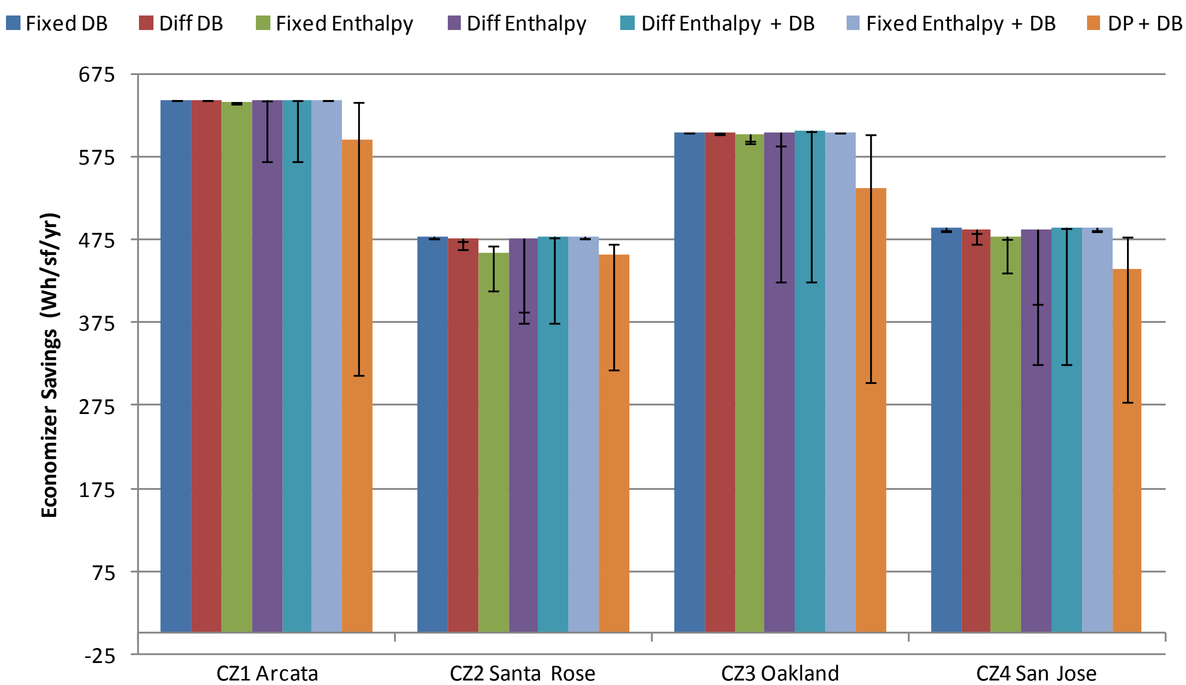


Figure 71. High Limit Control Performance – Climate Zones 1 - 4

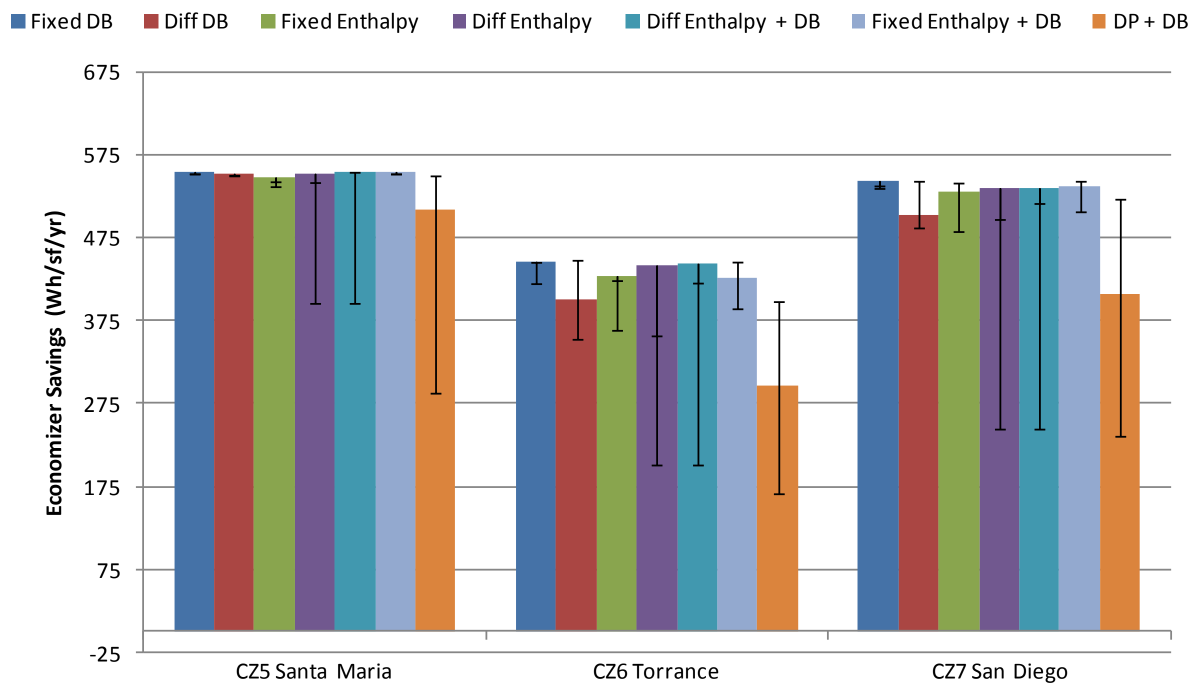


Figure 72. High Limit Control Performance – Climate Zones 5 - 7

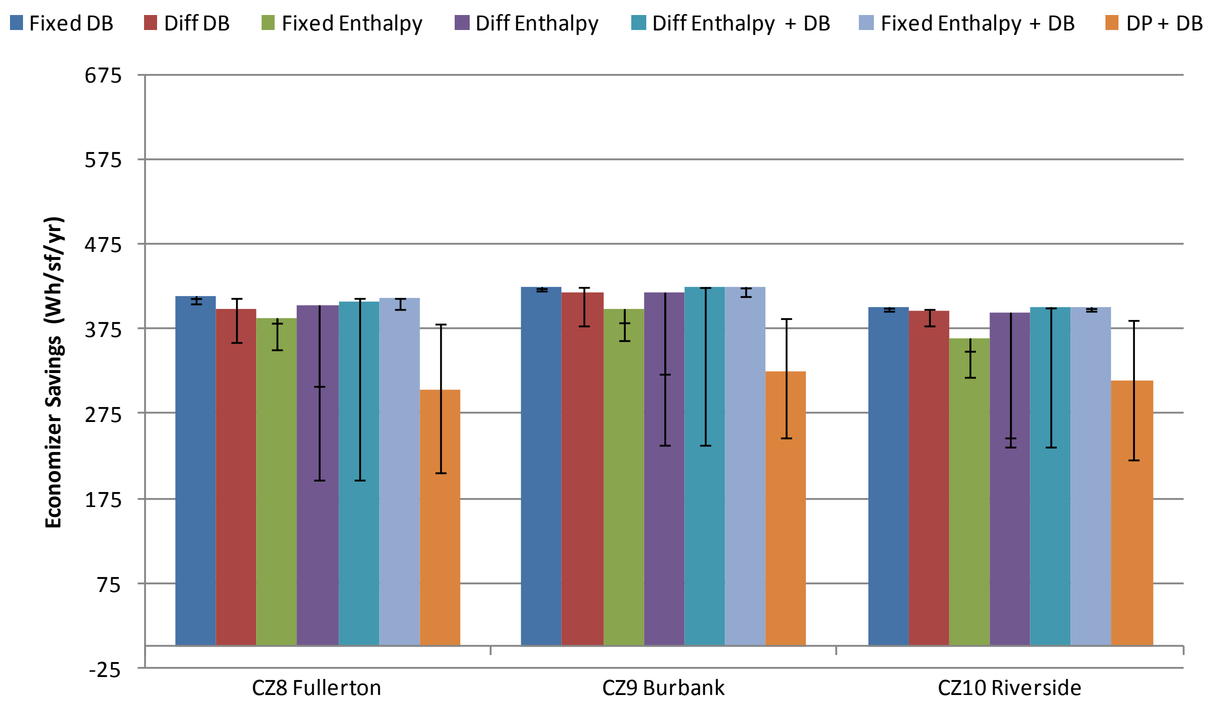


Figure 73. High Limit Control Performance – Climate Zones 8 - 10

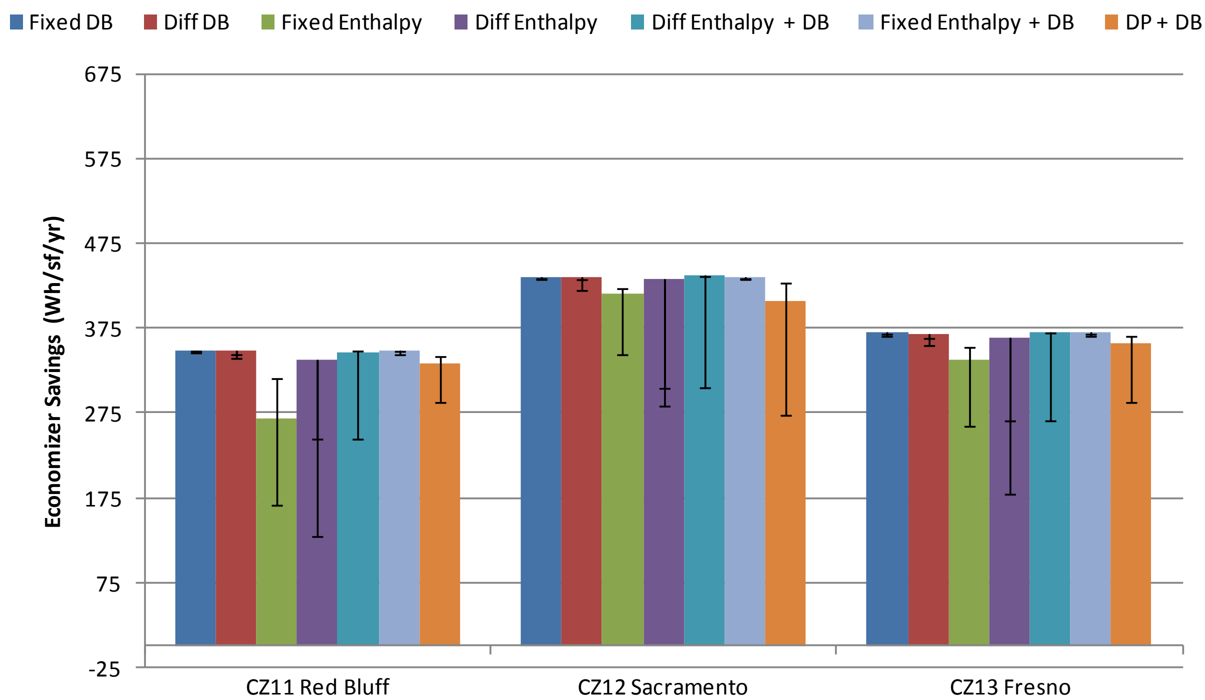


Figure 74. High Limit Control Performance – Climate Zone 11 - 13

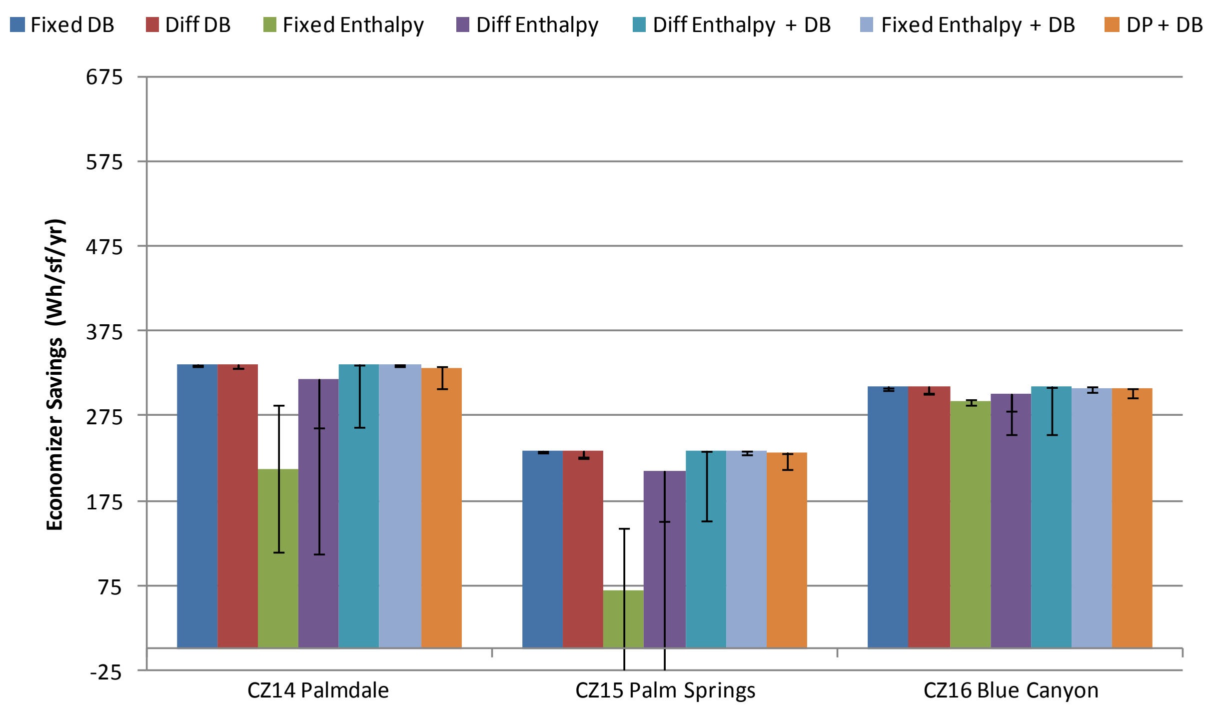


Figure 75. High Limit Control Performance – Climate Zones 14 - 16

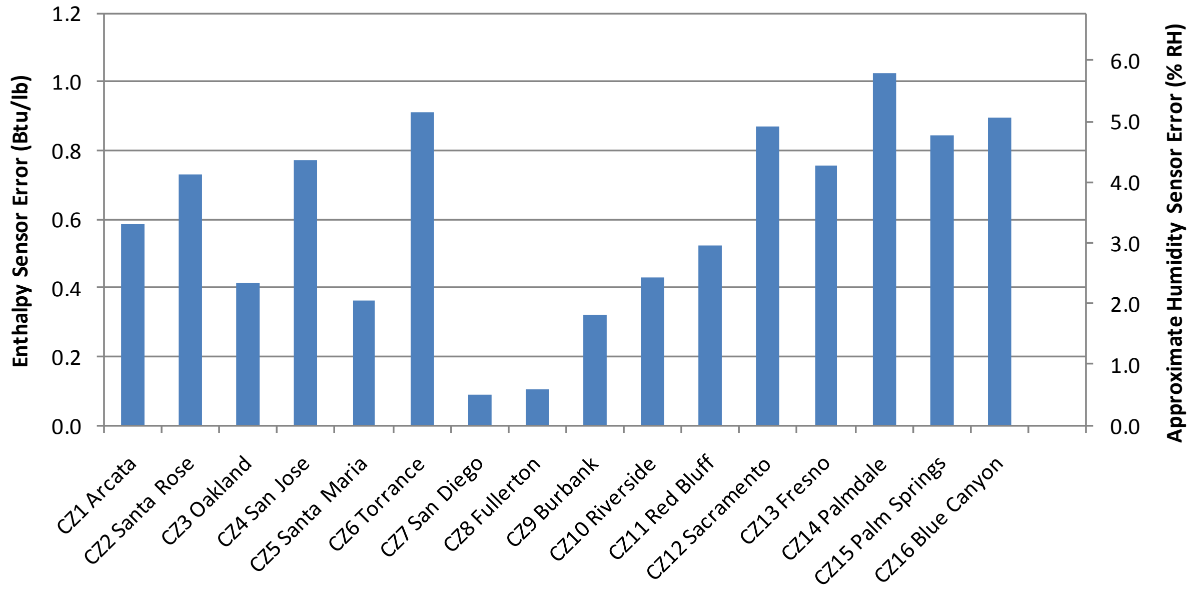


Figure 76. Required Maximum Dual Enthalpy Error to Match Fixed Drybulb with ±2°F Error

Conclusions that can be drawn from these results include:

1. Dual drybulb control should not be used in humid climates
2. Fixed enthalpy control should not be used in dry climates.
3. The best option, assuming no sensor error, is the combination of dual enthalpy and fixed drybulb. (Actually, the best option would have been dual enthalpy/dual drybulb but DOE-2.2 cannot model that option.)
4. Including sensor error, the best (or very close to the best) option in all climates is simply fixed drybulb control, assuming the setpoint is optimized by climate.
5. Including sensor error, the worst option in all climates is the dual enthalpy control. This control logic is considered the "best" anecdotally among many design engineers and is required for some climate zones by Standard 189.1, yet in practice with realistic (even optimistic) sensor error, it performs the worst among all options.
6. Fixed enthalpy control when combined with fixed drybulb control also performs well. The error in the enthalpy sensor is buffered by the addition of the drybulb limit, and the drybulb limit resolves the inefficiency problems the fixed enthalpy sensor has in dry climates. But it performs only slightly better than fixed drybulb alone even in humid climates, so it is not likely to be cost effective given the added first costs and maintenance (calibration) costs of the outdoor air humidity sensor.
7. The "electronic" enthalpy switch with an "A" setpoint imitates fixed enthalpy + fixed drybulb control and thus should perform fairly well in all climates provided it is as accurate as is assumed in Table 2. Recent research[xliv] has shown that the older electro-mechanical enthalpy switches are extremely inaccurate and that the most common solid-state enthalpy switches have on/off differentials on the order of the enthalpy error assumed in Table 2 (±2 Btu/lb_{da}) so that sensor error on top of that would make the performance worse. Plus, the "A" setting is

not quite as efficient as fixed enthalpy + fixed drybulb control per Figure 68. Finally, "electronic" enthalpy switches are hard to calibrate or to even know they are out of calibration. Thus, it is hard to justify the use of an "electronic" enthalpy switch over simple drybulb switch.

Fixed drybulb controls at the setpoints indicated in the proposed Standards language are the preferred high limit device for all climate zones due to their low first cost, inherently high energy efficiency, minimal sensor error and minimal impact even when there is sensor error, and low maintenance costs. The proposed fixed drybulb setpoints are optimized for each climate as described in Table 2 (see Appendix for detailed results). There is no added cost since these drybulb sensors are typically included in all systems and are a required component for all of the above strategies; therefore, no formal cost-effectiveness analysis is needed for this proposal.

Electricity savings per building and per square foot for each climate zone are provided in Table 3. There are no peak demand savings since economizer operation is during non peak conditions. There are no gas savings. The current standard allows multiple options for economizer high limits. For the purpose of documenting realistic savings, we have created a baseline with performance that represents a mix of strategies based on estimated installation rates. The baseline consists of a weighted average of the performance with a breakdown as follows:

- 30% fixed drybulb at currently prescribed setpoint
- 25% differential drybulb
- 5% fixed enthalpy at currently prescribed setpoint
- 10% differential enthalpy
- 30% electronic enthalpy on setting A (approximated in simulation as fixed enthalpy + fixed drybulb)

This proposed measure still allows the designer to choose among multiple strategies within each climate zone, however, the savings associated with the proposed scenario are based on the performance using the preferred fixed drybulb high limit. Both proposed and baseline cases account for sensor error as described in Table 2. Savings for each climate zone are shown in Table 3 and are based on a prototype building that is a single-story, office building that is 40,000 ft^2. Detailed energy savings tables are provided in the Appendices for each climate zone.

Climate Zone	Electricity Savings (kWh/yr)		TDV Electricity Savings	
	per Prototype Building	per square foot	per Prototype Building	per square foot
CZ1	346	0.009	1,235	0.031
CZ2	667	0.017	1,619	0.040
CZ3	715	0.018	1,738	0.043
CZ4	965	0.024	2,093	0.052
CZ5	605	0.015	1,047	0.026
CZ6	1,651	0.041	4,215	0.105
CZ7	2,001	0.050	7,175	0.179
CZ8	1,687	0.042	3,761	0.094
CZ9	1,082	0.027	2,568	0.064

CZ10	1,009	0.025	1,856	0.046
CZ11	1,161	0.029	5,088	0.127
CZ12	760	0.019	3,065	0.077
CZ13	979	0.024	2,714	0.068
CZ14	1,312	0.033	4,237	0.106
CZ15	1,697	0.042	3,417	0.085
CZ16	313	0.008	967	0.024

Table 3 – Energy Savings Summary

Conclusions & Recommendations

The results of our analysis suggest changes should be made to Title 24 with respect to economizer high limit controls. Fixed drybulb controls at the setpoint indicated are the preferred high limit device for all climate zones due to their low first cost, inherently high energy efficiency, minimal sensor error and minimal impact even when there is sensor error, and low maintenance costs. A similar analysis has been performed for Standards 90.1 and Standard 189.1[xlv] and changes to those standards have been formally proposed. Note that Fixed enthalpy, Fixed enthalpy + Fixed drybulb, and Electronic enthalpy are both acceptable in some or all climate zones but not recommended for use in any. This means they have acceptable performance in the climate zones listed, but they are not recommended since they will not be cost effective compared to fixed drybulb controls.

Recommended Language for Standards Document, ACM Manuals, and the Reference Appendices

SECTION 121 – REQUIREMENTS FOR VENTILATION

All nonresidential, high-rise residential, and hotel/motel occupancies shall comply with the requirements of Section 121(a) through 121(e).

…

(c) **Operation and Control Requirements for Minimum Quantities of Outdoor Air.**

1. **Times of occupancy**. The minimum rate of outdoor air required by Section 121(b)2 shall be supplied to each space at all times when the space is usually occupied.

   EXCEPTION 1 to Section 121(c)1: Demand control ventilation. In intermittently occupied spaces that do not have processes or operations that generate dusts, fumes, mists, vapors or gasses and are not provided with local exhaust ventilation (such as indoor operation of internal combustion engines or areas designated for unvented food service preparation), the rate of outdoor air may be reduced if the ventilation system serving the space is controlled by a demand control ventilation device complying with Section 121(c)4 <u>or by an occupant sensor ventilation control device complying with Section 121(c)5 or both</u>.

   EXCEPTION 2 to Section 121(c)1: Temporary reduction. The rate of outdoor air provided to a space may be reduced below the level required by Section 121(b)2 for up to 5 minutes each hour if the average rate for each hour is equal to or greater than the required ventilation rate.

   NOTE: VAV must comply with Section 121(c)1 at minimum supply airflow <u>except where occupancy is directly sensed using occupant sensor ventilation control complying with Section 121(c)5</u>.

   …

3. **Required Demand Control Ventilation**. HVAC systems with the following characteristics shall have demand ventilation controls complying with 121(c)4 or

   A. They have an air economizer; and

   B. They serve a space with a design occupant density, or a maximum occupant load factor for egress purposes in the CBC, greater than or equal to 25 people per 1000 ft^2 (40 square foot per person); and

   C. They are either:

      i. Single zone systems with any controls; or

      ii. Multiple zone systems with Direct Digital Controls (DDC) to the zone level.

   ....

   <u>**EXCEPTION 5 to Section 121(c)3:** Spaces with an area of less than 1,500 square feet complying with 121(c)5.</u>

<u>5. **Occupant Sensor Ventilation Control Devices**. Occupant sensors may be used to turn off ventilation dampers or fans when occupants are not present in accordance with the following:</u>

   <u>A. Occupant sensors shall meet requirements in Section 119 (d) and shall have suitable coverage and placement to detect occupants in the entire space ventilated. Occupant sensors controlling lighting may be used for ventilation as long as the ventilation signal is independent of daylighting or manual lighting overrides. Manual-on type lighting occupant sensors are not suitable for ventilation control.</u>

   <u>B. Where multiple rooms are served by a single zone box or ventilation fan, then each room shall have an occupant sensor and occupant detection in any room shall cause the fan and ventilation or zone box ventilation to operate and required ventilation shall continue for 15 minutes after all rooms served are vacant.</u>

C. Provisions shall be made for the daily building purge when required in Section 121(c)2 to override occupant sensor ventilation lockout.

D. Occupant sensor ventilation control may be used in conjunction with a demand control ventilation device complying with Section 121(c)4 that operates when occupancy is detected.

SECTION 122 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

122 (e) Shut-off and Reset Controls for Space-conditioning Systems. Each space-conditioning system shall be installed with controls that comply with Items ~~1 and 2~~ 1, 2, and 3 below:

1. The control shall be capable of automatically shutting off the system during periods of nonuse and shall have:

   A. An automatic time switch control with a manual override that allows operation of the system for up to 4 hours; or

   B. An occupancy sensor; or

   C. A 4-hour timer that can be manually operated.

   EXCEPTION to Section 122(e)1: Mechanical systems serving retail stores and associated malls, restaurants, grocery stores, churches, and theaters equipped with 7-day programmable timers.

2. The control shall automatically restart and temporarily operate the system as required to maintain:

   A. A setback heating thermostat setpoint if the system provides mechanical heating; and

      EXCEPTION to Section 122(e)2A: Thermostat setback controls are not required in nonresidential buildings in areas where the Winter Median of Extremes outdoor air temperature determined in accordance with Section 144(b)4 is greater than 32°F.

   B. A setup cooling thermostat setpoint if the system provides mechanical cooling.

      EXCEPTION to Section 122(e)2B: Thermostat setup controls are not required in nonresidential buildings in areas where the Summer Design Dry Bulb 0.5 percent temperature determined in accordance with Section 144(b)4 is less than 100°F.

3. Multipurpose rooms of less than 1000 square feet, and classrooms and conference rooms of any size, shall be equipped with occupant sensor(s) to setup the operating cooling temperature set point to 75°F or higher and setback the operating heating temperature set point to 68˚F or lower when served by a VAV system..

EXCEPTION 1 to Section 122(e): Where it can be demonstrated to the satisfaction of the enforcing agency that the system serves an area that must operate continuously.

EXCEPTION 2 to Section 122(e): Where it can be demonstrated to the satisfaction of the enforcing agency that shutdown, setback, and setup will not result in a decrease in overall building source energy use.

EXCEPTION 3 to Section 122(e): Systems with full load demands of 2 kW or less, if they have a readily accessible manual shut-off switch.

EXCEPTION 4 to Section 122(e): Systems serving hotel/motel guest rooms, if they have a readily accessible manual shut-off switch.

SECTION 125 – REQUIRED NONRESIDENTIAL MECHANICAL SYSTEM ACCEPTANCE

(a) Before an occupancy permit is granted the following equipment and systems shall be certified as meeting the Acceptance Requirements for Code Compliance, as specified by the Reference Nonresidential Appendix NA7. A Certificate of Acceptance shall be submitted to the enforcement agency that certifies that the equipment and systems meet the acceptance requirements:

1. Outdoor air ventilation systems shall be tested in accordance with NA7.5.1
2. Constant volume, single zone unitary air conditioning and heat pump unit controls shall be tested in accordance with NA7.5.2.
3. Duct systems shall be tested in accordance with NA7.5.3 where either:
   A. They are new duct systems that meet the criteria of Sections 144(k)1, 144(k)2, and 144(k)3; or
   B. They are part of a system that meets the criteria of Section 149(b)1D.
4. Air economizers shall be tested in accordance with NA7.5.4.

   EXCEPTION to Section 125(a)4: Air economizers installed by the HVAC system manufacturer and certified to the Commission as being factory calibrated and tested are exempted from the Functional Testing section of the Air Economizer Controls acceptance test as described in ~~not required to be field tested per~~ NA7.5.4.2.

SECTION 144 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

A building complies with this section by being designed with and having constructed and installed a space-conditioning system that meets the requirements of Subsections (a) through ~~(l)~~(m).

144 (e) Economizers.

1. Each individual cooling fan system that has a design supply capacity over ~~2,500~~ 1,800 cfm and a total mechanical cooling capacity over ~~75,000~~ 54,000 Btu/hr shall include either:

   A. An air economizer capable of modulating outside-air and return-air dampers to supply 100 percent of the design supply air quantity as outside-air; or

   B. A water economizer capable of providing 100 percent of the expected system cooling load as calculated in accordance with a method approved by the Commission, at outside air temperatures of 50°F dry-bulb/45°F wet-bulb and below.

   EXCEPTION 1 to Section 144(e)1: Where it can be shown to the satisfaction of the enforcing agency that special outside air filtration and treatment, for the reduction and treatment of unusual outdoor contaminants, makes compliance infeasible.

   EXCEPTION 2 to Section 144(e)1: Where the use of outdoor air for cooling will affect other systems, such as humidification, dehumidification, or supermarket refrigeration systems, so as to increase overall building TDV energy use.

   EXCEPTION 3 to Section 144(e)1: Systems serving high-rise residential living quarters and hotel/motel guest rooms.

   EXCEPTION 4 to Section 144(e)1: Where it can be shown to the satisfaction of the enforcing agency that the use of outdoor air is detrimental to equipment or materials in a space or room served by a dedicated space-conditioning system, such as a computer room or telecommunications equipment room.

EXCEPTION 5 to Section 144(e)1: Where electrically operated unitary air conditioners and heat pumps have cooling efficiencies that meet or exceed the efficiency requirements of TABLE 144-A and TABLE 144-B.

2. If an economizer is ~~required by Subparagraph 1~~installed, it shall be:

   A. Designed and equipped with controls so that economizer operation does not increase the building heating energy use during normal operation; and

      EXCEPTION to Section 144(e)2A: Systems that provide 75 percent of the annual energy used for mechanical heating from site-recovered energy or a site-solar energy source.

   B. Capable of providing partial cooling even when additional mechanical cooling is required to meet the remainder of the cooling load.

      i. Unitary systems with an economizer shall have control systems, including two-stage or electronic thermostats, that cycle compressors off when economizers can provide partial cooling.

      ii. Mechanical cooling shall be capable of staging or modulating capacity in increments of no more than 50% of total cooling capacity for unitary systems greater than 65,000 Btu/hr at ARI conditions and no more than 20% of total cooling capacity for chilled water or built-up systems. Controls shall not false load the mechanical cooling system by limiting or disabling the economizer or any other means, such as hot gas bypass, except at the lowest stage of cooling capacity.

3. Air economizers shall have high limit shutoff controls complying with TABLE 144-C.

4. Air economizers and return air dampers on an individual cooling fan system that has a design supply capacity over 1,500 cfm and a total mechanical cooling capacity over 45,000 Btu/hr shall have the following features:

      i. Warrantee. 5-year performance warranty of economizer assembly

      ii. Drive mechanism. Economizer and return dampers have a direct drive modulating actuator with gear driven interconnections

      iii. Damper reliability testing. Economizer and return damper certified that representative products have been tested and are able to open against the rated airflow and pressure of the system after 100,000 damper opening and closing cycles.

      iv. Damper leakage. Economizer and return dampers shall be certified to have a maximum leakage rate of 10 cfm/sf at 1.0 in. w.g. when tested in accordance with AMCA Standard 500.

      v. Adjustable setpoint. If the high-limit control is fixed dry-bulb,or fixed enthalpy it shall have an adjustable setpoint

      vi. Damper control sensor location. Primary damper control temperature sensor located after the cooling coil to maintain comfort

      vii. Sensor accuracy. Outdoor air, return air and supply air sensors are calibrated within the following accuracies.

         1. Drybulb and wetbulb temperatures accurate to ± 1°F

         2. Enthalpy accurate to within ± 1 Btu/lb

         3. Relative humidity accurate to within 5%

      viii. Sensor calibration data of sensors used for control of economizer are plotted on sensor performance curve.

      ix. Sensors used for the high limit control are located to prevent false readings, e.g. properly shielded from direct sunlight.

      x. Relief air. System is designed to provide up to 100% outside air without over-pressurizing the building

(m) **Fault Detection and Diagnostics (FDD) for Packaged Direct-Expansion Units.** All packaged direct-expansion units with mechanical cooling capacity at ARI conditions greater than or equal to 54,000 Btu/hr shall include a Fault Detection and Diagnostics (FDD) system in accordance with NA9 – Fault Detection and Diagnostics.

…

TABLE 144-C AIR ECONOMIZER HIGH LIMIT SHUT OFF CONTROL REQUIREMENTS

Device Type[a]	Climate Zones	Required High Limit (Economizer Off When):	
		Equation[b]	Description
Fixed Dry Bulb	~~*1, 2, 3, 5, 11, 13, 14, 15 & 16*~~**1, 3, 5, 11-16**	T_{OA} > 75°°F	Outdoor air temperature exceeds 75°F
	2, 4, 10	**T_{OA} > 73°°F**	**Outdoor air temperature exceeds 73°F**
	6, 8, 9	**T_{OA} > 71°°F**	**Outdoor air temperature exceeds 71°F**
	7	**T_{OA} > 69°°F**	**Outdoor air temperature exceeds 69°F**
	~~*4, 6, 7, 8, 9, 10 & 12*~~	~~*T_{OA} > 70°°F*~~	~~*Outdoor air temperature exceeds 70°F*~~
Differential Dry Bulb	~~*All*~~**1-5, 10-16**	T_{OA} > T_{RA}	Outdoor air temperature exceeds return air temperature
~~*Fixed Enthalpy[a]*~~	~~*4, 6, 7, 8, 9, 10 & 12*~~	~~*h_{OA} > 28 Btu/lb[b]*~~	~~*Outdoor air enthalpy exceeds 28 Btu/lb of dry air[b]*~~
Fixed Enthalpy + Fixed Drybulb	**All**	**h_{OA} > 28 Btu/lb[c] or** **T_{OA} > 75°°F**	**Outdoor air enthalpy exceeds 28 Btu/lb of dry air[c] or** **Outdoor air temperature exceeds 75°F**
Electronic Enthalpy	All	(T_{OA}, RH_{OA}) > A	Outdoor air temperature/RH exceeds the "A" set-point curve~~c~~**d**
~~*Differential Enthalpy*~~	~~*All*~~	~~*h_{OA} > h_{RA}*~~	~~*Outdoor air enthalpy exceeds return air enthalpy*~~

[a] Fixed Enthalpy **and Differential Enthalpy** Controls are prohibited in **all** climate zones ~~*1, 2, 3, 5, 11, 13, 14, 15 & 16*~~.

[b] **Devices with selectable (rather than adjustable) setpoints shall be capable of being set to within 2°F and 2 Btu/lb of the setpoint listed.**

[~~b~~**c**] At altitudes substantially different than sea level, the Fixed Enthalpy limit value shall be set to the enthalpy value at 75°F and 50% relative humidity. As an example, at approximately 6000 foot elevation the fixed enthalpy limit is approximately 30.7 Btu/lb.

[~~c~~**d**] Set point "A" corresponds to a curve on the psychometric chart that goes through a point at approximately 75°F and 40% relative humidity and is nearly parallel to dry bulb lines at low humidity levels and nearly parallel to enthalpy lines at high humidity levels.

SECTION 149 – ADDITIONS, ALTERATIONS, AND REPAIRS TO EXISTING BUILDINGS THAT WILL BE NONRESIDENTIAL, HIGH-RISE RESIDENTIAL, AND HOTEL/MOTEL OCCUPANCIES AND TO EXISTING OUTDOOR LIGHTING FOR THESE OCCUPANCIES AND TO INTERNALLY AND EXTERNALLY ILLUMINATED SIGNS

Section 149(b)1E

E. When a space conditioning system is altered by the installation or replacement of space conditioning equipment (including replacement of the air handler, outdoor condensing unit of a split system air conditioner or heat pump, cooling or heating coil, or the furnace heat exchanger);

1. Existing non-setback thermostats shall be replaced with setback thermostats for all altered units. All newly installed space conditioning systems requiring a thermostat shall be equipped with a setback thermostat. All setback thermostats shall meet the requirements of Section 112(c); and

2. Unitary systems with an economizer shall have control systems, including two-stage or electronic thermostats, that cycle compressors off when economizers can provide partial cooling; and

2. 3. The duct system that is connected to the new or replaced space conditioning equipment, if the duct system meets the criteria of Sections 144(k)1, 2, and 3, shall be sealed, as confirmed through field verification and diagnostic testing in accordance with procedures for duct sealing of existing duct systems as specified in the Reference Nonresidential Appendix NA2, to one of the requirements of Section 149(b)1D.

EXCEPTION 1 to Section 149(b)1E: Buildings altered so that the duct system no longer meets the criteria of Sections 144 (k)1, 2, and 3.

EXCEPTION 2 to Section 149(b)1E: Duct systems that are documented to have been previously sealed as confirmed through field verification and diagnostic testing in accordance with procedures in the Reference Nonresidential Appendix NA2.
EXCEPTION 3 to Section 149(b)1E: Existing duct systems constructed, insulated or sealed with asbestos.

Nonresidential Appendix NA7 – 2013

Appendix NA7 – Acceptance Requirements for Nonresidential Buildings

…

NA7.5.4 Air Economizer Controls (Certificate of Acceptance Form MECH-5A)

NA7.5.4.1 Construction Inspection

Prior to Functional Testing, verify and document the following:

- Economizer lockout setpoint complies with Table 144-C of Standards §144(e)3.
- If the high-limit control is fixed dry-bulb, it shall have an adjustable setpoint.
- Economizer lockout control sensor is located to prevent false readings.
- Sensor performance curve is provided by factory with economizer instruction material
- Sensor output value measured during sensor calibration is plotted on the performance curve
- Primary damper control temperature sensor located after the cooling coil to maintain comfort
- Economizer damper moves freely without binding.
- Unitary systems with an economizer have control systems, including two-stage or electronic thermostats, that cycle compressors off when economizers can provide partial cooling
- System is designed to provide up to 100 percent outside air without over-pressurizing the building.
- For systems with DDC controls lockout sensor(s) are either factory calibrated or field calibrated.
- For systems with non-DDC controls, manufacturer's startup and testing procedures have been applied
- Provide an economizer specification sheet proving capability of at least 100,000 actuations
- Provide a product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf

- Unit has a direct drive modulating actuator with gear driven interconnections

NA7.5.4.2 Functional Testing

Step 1: Disable demand control ventilation systems (if applicable).

Step 2: Enable the economizer and simulate a cooling demand large enough to drive the economizer fully open. Verify and document the following:

- Economizer damper is 100 percent open and return air damper is 100 percent closed.
- For systems that meet the criteria of Standards §144(e)1, verify that the economizer provides partial cooling even when additional mechanical cooling is required to meet the remainder of the cooling load ~~remains 100 percent open when the cooling demand can no longer be met by the economizer alone~~.
- All applicable fans and dampers operate as intended to maintain building pressure.
- The unit heating is disabled (if unit has heating capability).

Step 3: Disable the economizer and simulate a cooling demand. Verify and document the following:

- Economizer damper closes to its minimum position.
- All applicable fans and dampers operate as intended to maintain building pressure.
- The unit heating is disabled (if unit has heating capability).

Step 4: If the unit has heating capability, simulate a heating demand and set the economizer so that it is capable of operating (i.e. actual outdoor air conditions are below lockout setpoint). Verify the following:

- The economizer is at minimum position
- Return air damper opens

Step 5: Turn off the unit. Verify and document the following:

- Economizer damper closes completely.

Step ~~5~~6: Restore demand control ventilation systems (if applicable) and remove all system overrides initiated during the test.

Nonresidential Appendix NA9 – 2013

Appendix NA9 – Fault Detection and Diagnostics

NA9.1 System Requirements

The following sensors should be permanently installed to monitor system operation and the controller should have the capability of displaying the value of each parameter:

- Refrigerant pressure: suction line, liquid line
- Refrigerant temperature: suction line, liquid line
- Air relative humidity: outside air, supply air
- Air temperature: outside air, supply air, return air

The controller shall provide system status by indicating the following conditions:

- Compressor enabled
- Free cooling available

- Heating enabled
- Economizer enabled
- Mixed air low limit cycle active

The unit controller shall manually initiate each operating mode so that the operation of compressors, economizers, fans, and heating system can be independently tested and verified.

Faults shall be reported to a fault management application accessible by day-to-day operating or service personnel, or annunciated locally on zone thermostats.

A performance indicator shall be provided, which will allow tracking of efficiency.

The FDD System used shall be certified by the CEC and verified to be installed correctly.

NA9.2 Faults to be Detected

The FDD system shall detect the following faults:

- Air temperature sensor failure/fault
- Low refrigerant charge
- Not economizing when it should
- Economizing when it should not
- Damper not modulating
- Excess outdoor air

Nonresidential ACM Manual

2.5.3.7 Air Economizers

Description:	The reference method is capable of simulating an economizer that: (1) modulates outside air and return rates to supply up to 100 percent of design supply air quantity as outside air; and, (2) modulates to a fixed position at which the minimum ventilation air is supplied when the economizer is not in operation. The reference method will simulate at least two types of economizers and all Compliance software shall receive input for these two types of economizers: 1. *Integrated*. The economizer is capable of providing partial cooling, even when additional mechanical cooling is required to meet the remainder of the cooling load. The economizer is shut off when outside air temperature or enthalpy is greater than a fixed setpoint. 2. *Nonintegrated/fixed set point.* This strategy allows only the economizer to operate below a fixed outside air temperature set point. Above that set point, only the compressor can provide cooling.
DOE-2 Keyword(s)	ECONO-LIMIT ECONO-LOCKOUT ECONO-LOW-LIMIT
Input Type	Default
Tradeoffs	Yes
Modeling Rules for	The compliance software shall allow the user to input either an *integrated* or *non-*

Proposed Design:	*integrated* economizer as described above as it occurs in the construction documents. The compliance software shall require the user to input the ODB set point. For systems with economizers, the maximum outside air fraction (keyword MAX-OA-FRACTION) shall be set to 0.9.
Default:	No Economizer
Modeling Rules for Standard Design (New):	The standard design shall assume an *integrated* air economizer, available for cooling any time ODB < T_{limit}, on systems 1, 2, 3 and 4 (See Standard Design Systems Types) when mechanical cooling output capacity of the proposed design as modeled in the compliance run by the compliance software is over 75,000 Btu/hr and fan system volumetric capacity of the proposed design as modeled in the compliance run by the compliance software is over 2500 cfm. T_{limit} shall be set to 75°F for climate zones ~~*1, 2, 3, 5, 11, 13, 14, 15 & 16*~~**1, 3, 5 & 11-16**. T_{limit} shall be set to ~~*70*~~**73**°F for climate zones ~~*4, 6, 7, 8, 9, 10 & 12*~~**2, 4 & 10**. **T_{limit} shall be set to 71°F for climate zones 6, 8 & 9. T_{limit} shall be set to 69°F for climate zone 7**. The compliance software shall not assume economizers on any system serving high-rise residential and hotel/motel guest room occupancies.
Modeling Rules for Standard Design (Existing Unchanged & Altered Existing):	All Compliance software shall model existing economizers as they occur in the existing building.

Bibliography and Other Research

FDD: Moving the Market and Informing Title 24

Heinemeier, Kristin, (WCEC), Mark Cherniack (NBI), and Julien Bec (UCD). 2010. *Fault Detection And Diagnostics, Moving The Market And Informing Standards In California*. California Energy Commission.

This first phase of this project identified and prioritized the faults that can be detected by a set of currently (or shortly) available diagnostic tools, and evaluated the available tools. One crucial part of this prioritization is collecting intelligence from key stakeholders. In this report, the authors describe the process of developing an interview guide and carrying out a small set of interviews. They summarize the interviews that were held, as well as provide the detailed responses to their list of questions. This paper describes development of a draft specification for new requirements for FDD in Rooftop Units. The authors also held an industry roundtable to present the draft to a set of industry actors, and obtain their feedback.

Common Faults and Their Impacts for Rooftop Air Conditioners

Breuker, M.S., and J.E. Braun. 1998 "Common Faults and Their Impacts for Rooftop Air Conditioners." HVAC&R Research, Vol. 4, No. 3, July.

In this study, different common faults were artificially introduced in an RTU and the impact on energy efficiency and COP was evaluated.

Commercial Rooftop HVAC Energy Savings Research Program DRAFT Final Project Report

Cherniack, M., Reichmuth, H. New Buildings Institute. *Commercial Rooftop HVAC Energy Savings Research Program Final Project Report (DRAFT).* Prepared for Northwest Power and Conservation Council. March 25, 2009.

This paper documents the portion of the research pertaining to the bench testing of economizer controls that was done as part of the Commercial Rooftop HVAC Energy Savings Research Program.

Findings/Discussions include:

- Overall energy use is reduced with wider temperature control setpoints and more aggressive use of pre-cooling. The temperature range at which an economizer operates is typically too narrow for optimal energy use (i.e. economizer may turn off at a temperature only a degree cooler than it turned on). For best operation, the economizer needs to allow cool air to enter the building earlier and continue allowing ventilation air longer than is typical with compressor control.
- Controller and temperature sensors are biased (though amount of bias varied) toward lower temperature settings (sensors activated economizer operation at temperatures lower than actual temperature). The wide sensor tolerance leads to loss of economizer energy saving

potential. If an economizer allows air to enter the building that is cooler than what is required, it could lead to unnecessary reheat energy waste.
- Hysteresis discussed: concept that the controller deadband can interfere with expected economizer operation by limiting potential during seasons with warm nights.
- Typical 6-10 degree F deadband may limit economizer operation.
- Outdoor dry bulb sensor tested (controlled by varying the OAT between upper and lower limits. As the OA temperature cycled, the status of the dampers was recorded).
  - Findings: Large lag in response time. Typical: 12 minutes for 1˚F temperature change.
  - Time to reach system equilibrium: 1 hour.

The Premium Economizer: An Idea Whose Time Has Come

Hart, R., Morehouse, D., Price, W. Eugene Water & Electric Board. *The Premium Economizer: An Idea Whose Time Has Come*. ACEEE Summer Study on Energy Efficiency in Buildings. 2006.

Field studies have found that more than half of outside air economizers on packaged rooftop units are not functioning properly, and therefore not providing energy savings because dampers or controls have failed, changeover is set incorrectly, or climate appropriate controls have not been installed. Analysis of economizer operation indicates that, at best, only one-third of potential savings is being achieved.

Outdoor air economizer shows great savings potential in energy simulations, however the actual performance has been much less than ideal.

Most packaged HVAC units have coordinated activation - the economizer is activated on a call for cooling from the thermostat. Older economizers use fixed air temperature control, resulting in high energy use.

Integration means that an economizer is “capable of providing partial cooling even when additional mechanical cooling is required to meet the cooling load”. Five levels of integration exist, as discussed below:

- Non Integrated (exclusive operation): Below changeover setting - economizing only; Above changeover setting - mechanical cooling.
- Time delay integration: on a call for cooling, economizer operates for a set period of time (typically 5 minutes). If there is still need for cooling, the cooling coil operates.
- Alternating integration: first cooling call activates economizer; second call engages compressor and economizer dampers reduce OSA (to avoid discomfort) from discharge air that is too cold.
- Partial integration: multi-stage compressor integration is improved since systems provide partial cooling. The partial mechanical cooling provides less temperature drop so that when the compressor is on, the economizer can use a lower outside air temperature and do more outside air cooling than in alternating integration.
- Full integration: This allows economizer to operate at the same time as mechanical cooling.

The table below shows a summary of standard, better than standard, and premium economizer features that were monitored in this study.

Attribute	Standard	Better than Standard	Premium
Configuration	Modulating RA/OA dampers, no relief	Modulating RA/OA dampers, barometric relief	Modulating RA/OA dampers, barometric relief
Activation	Single stage cooling	Single stage cooling	Two Stage Cooling
Changeover	Snap Disc 55ºF OSA dry-bulb	Settable 60ºF OSA dry-bulb	Differential dry-bulb
Integration	None	None	Alternating integration
Ventilation (min)	"eyeball" estimate	CO2 meter used once to set at site "A," eyeball at site "B."	Set using measured temperatures to calculate outside air fraction.

Premium economizers provide greater energy savings because they provide alternating or partial integration. In addition to the standard characteristics, a premium economizer also has the following attributes:

- Dedicated thermostat stage for economizer
- Differential dry-bulb changeover
- Primary control placement
- Low-ambient OSA compressor lockout
- Installer training

Small HVAC System Design Guide

Architectural Energy Corporation. *Small HVAC System Design Guide*. Prepared for the California Energy Commission. October 2003.

Target audience: architects, engineers, and design/build contractors involved in the design of small packaged rooftop systems for commercial building applications.

Small HVAC systems are installed in about 40 million square feet of new California construction annually. By applying the integrated design principles in this guide, energy consumption and construction costs of buildings with small HVAC system can be reduced up to 35 percent. This document is targeted at buildings with small, package HVAC systems (up to 10 tons/unit) given the fact that units of this size are notorious for consuming more energy that is necessary.

This project looked at 215 rooftop units on 75 buildings in California. Of the 215 units tested, 123 were equipped with economizers. Through field monitoring and testing, a number of common installation and operation problems were identified. Frequently, problems with equipment and controls (economizers, fan controls, thermostat programming), in-situ air flow and fan power, refrigerant charge, and operation/maintenance practices that can lead to poor system performance are addressed in this paper and summarized below:

- Economizers: In this study, economizers show a high rate of failure. Of the units equipped with an economizer, 64% were not operating correctly. Failure modes include: inoperable dampers, sensor/control failure and poor operation. The average energy impact of inoperable economizer is approximately 37% of the annual cooling energy.
- Economizer Changeover Setpoint: Changeover setpoint has a major influence on the energy savings potential on an economizer. If the changeover setpoint is set too low, mechanical cooling will operate exclusively, even when the economizer is capable of meeting all or a portion of the cooling load.
- Refrigerant Charge: 46% of the units tested were not properly charged, which resulted in reductions in cooling capacity and/or unit efficiency: 15% were 5% undercharged, while 8% of the units had refrigerant leaks. The variability in efficiency is a function of refrigerant charge. Units with a thermostatic expansion valve (TXV) show much less variation in unit efficiency as the TXV can compensate to some degree for improper charge. The average energy impact of refrigerant charge problems was about 5% of the annual cooling energy.
- Low air flow: 39% of the units tested had low air flow rates. The average flow rate of all units tested was 325 cfm/ton, which is about 20% less than the flow rates used to rate efficiency. Reduced air flow results in reduced unit efficiency and cooling capacity. The annual energy impact of low air flow is about 7% of the annual cooling energy.
- Integrated Design Practices: By including “load avoidance” strategies in design, the size and energy consumption of the HVAC system can be reduced. The first costs of the load avoidance strategies are generally offset by reductions in the HVAC and distribution system size and cost. These strategies include: energy efficient lighting, high performance fenestration systems, use of cool roofing materials, and enhanced roof insulation, and proper HVAC unit location.
- Unit Sizing: To take full benefit of an integrated design approach, sizing methods that are responsive to load avoidance strategies should be employed. Many HVAC units are oversized, resulting in inefficient operation, reduced reliability due to frequent cycling of compressors and poor humidity controls. Other design practices that should be employed are: use reasonable assumptions for plug loads, use reasonable assumptions for ventilation air quantities, and avoid oversizing.
- Unit Selection: Select rooftop units that meet CEE Tier 2 efficiency standards and employ features that improve the efficiency and reliability of the units, including, but not limited to premium efficiency fan motors, thermostatic expansion valves, and factory run tested economizers. Unit should be selected based on actual design conditions (as opposed to nominal values) and design features specified that improve serviceability.
- Distribution Systems: After the HVAC unit, the distribution system is the most important (and costly) part of the HVAC system. Proper layout and design is essential. Duct system pressure drop should be minimized to allow systems to operate at the design flow rate.
- Ventilation: Providing adequate ventilation is the key component of indoor air quality. Strategies to provide adequate ventilation are often at odds with energy efficiency; however, it should the priority of designers and operators of buildings to meet ventilation code requirements first, and then meet these requirements in the most energy-efficient manner possible. Design points to consider include: continuous operation of unit fans to meet ventilation requirements while using demand controlled ventilation to modulate airflow in the zones.

- Thermostats and Controls: Two-stage cooling thermostats should be specified that have the ability to schedule thermostat setpoints, fan schedule, and fan operating mode independently. Locate thermostats in the zone served by its HVAC unit. The thermostat should be programmed for auto-mode (not continuous) fan operation during unoccupied hours, and provide a one hour pre-purge of the building prior to occupancy.
- Commissioning: Commission the system to ensure that the intent of the designer is met in the building as constructed. Verify proper unit installation using pre-functional checklists and verify unit operation using functional performance tests of control sequences, fan power, air flowrate, economizer operation, and refrigerant charge. Pre-functional and functional testing procedures that are not currently included in acceptance testing will be incorporated into CASE work if appropriate, such as verify correct rotation of supply and condenser fan motors.

HVAC CASE Study for 2001 Nonresidential Title 24

Eilert, P., Pacific Gas and Electric Company. *Heating, Ventilation and Air Conditioning (HVAC) Controls – Codes and Standards (CASE) Study*. November 28, 2000.

This CASE study covers the following topics in support of 2001 Title 24:

- Economizer controls
- Diagnostic systems (FDD)
- Thermostats and fan controls

Proposed changes/findings included in this report are as follows:

- Require certification of thermostats and other fan system controllers.
- Development of economizer testing standards by a national standards organization (ASHRAE, AHRI). The standard would establish minimum criteria for failure, sensor location, etc to improve the long term reliability of economizers.
- Expand the current economizer requirements to cover all units above 3-ton capacity. Units under 6.25 tons may comply using a non-integrated economizer.
- A voluntary program to address economizer and thermostat system performance could be initiated with the help of the Consortium for Energy Efficiency. This program would promote reliable mechanical linkages, automated diagnostics, and control strategies.

Key stakeholders include packaged unitary equipment manufacturers and their suppliers, and electronic thermostat control manufacturers. The HVAC equipment manufacturer suppliers are an important element, since many manufacturers rely on outside vendors such as Cannon Fabrication (Canfab) to provide key components such as add-on economizer systems (controls, actuators and damper packages), and Honeywell and Johnson Controls to supply integrated packaged system controllers.

Other key stakeholders include building owners and contractors, who will need to be convinced of the benefits derived from the added cost of requiring economizers on small systems. Improvements in indoor air quality may help persuade this group of the value of the proposed change.

Energy Smart Design - Office Package B (Technical Specifications)

Regional Technical Forum. *Energy Smart Design - Office Package B (Technical Specifications).* May 7, 2008.

This document outlines the requirements for enhanced economizers as developed by the Regional Technical Forum (RTF) as part of the Energy Smart Office Design Package. The enhanced economizers are part of a prescriptive design path. This document requires the listed features in a minimum of 70 percent of conditioned floor area. Verification shall be performed during the commissioning process.

Part 1. Enhanced Economizer Requirements

- *Fully modulating damper motor*: A fully modulating damper motor shall allow proper mixed air temperature control and maximize economizer operating hours.
- *Damper drive mechanism*: A direct modulating actuator with gear-driven interconnections and a permanently lubricated bushing or bearing on the outside and return air dampers shall be installed.
- *Primary damper-control sensor*: The primary damper-control sensor, sometimes referred to as the mixed-air or discharge-air sensor, shall be located in the discharge air position after the cooling coil or in the supply duct.
- *Relief air and modulating return air damper*: Relief air shall be provided with a barometric damper in the return air duct upstream of the return air damper, a motorized exhaust air damper or an exhaust fan.
- *Minimum outside air (OSA) ventilation*: The minimum OSA ventilation shall be verified. If verified by air temperature measurement, the temperature of the mixed air, return air and outside air shall be used to calculate the percentage of outside air at the minimum setting. Verification by measuring OSA with a flow hood, flow plate or other is also acceptable. The final minimum OSA ventilation shall be adjusted to the amount indicated in the designer's sequence of operation.
- *Dedicated thermostat stage for economizer*: A thermostat with two stages of cooling, with the primary cooling stage dedicated to economizer control, shall be installed so the economizer satisfies the cooling load before the mechanical compressor is enabled.
- *Differential changeover with both a return and outside air sensor*: The economizer controller shall utilize differential logic, a dry-bulb return air sensor, and outside air sensor for differential changeover. In western climates, high humidity rarely occurs near changeover temperatures, and dry-bulb sensors provide higher expected reliability at lower cost than enthalpy sensors. If the economizer controller has a changeover selector, this shall be set to the differential/comparative control position per manufacturer's instructions.
- Outside air changeover set point shall be between 55°and 65°F, Honeywell dry bulb changeover control "D" setting, or equivalent.
- System controls are wired correctly to ensure economizer is fully integrated (i.e. economizer will operate when mechanical cooling is enabled).
- Economizer lockout control sensor location is adequate (open to air but not exposed to direct sunlight nor in an enclosure; away from sources of building exhaust.

- If no relief fan system is installed, barometric relief dampers are installed to relieve building pressure when the economizer is operating.

Part 2. Economizer Functional Testing Procedure: Simulate a cooling load and enable the economizer by adjusting the lockout control set point. Verify and document the following:

- Economizer damper modulates open to maximum position to satisfy cooling space temperature set point.
- Return air damper modulates closed and is completely closed when economizer damper is 100% open.
- Economizer damper is 100% open before mechanical cooling is enabled.
- Relief fan is operating or relief dampers freely swing open.
- Mechanical cooling is only enabled if cooling space temperature set point is not met with the economizer at 100% open.
- Relief fan system (if installed) operates only when the economizer is enabled.
- Doors are not pushed ajar from over pressurization..

Part 3. Economizer Shut Down Procedure: Disable the economizer by adjusting the lockout control set point. Verify and document the following:

- Outside air damper closes to minimum position when economizer is disabled.
- Relief fan shuts off or relief or barometric dampers close when economizer is disabled.
- Mechanical cooling remains enabled until cooling space temperature set point is met.
- Return air damper opens to normal operating position.
- Outside air damper closes completely when unit is off.

Nonresidential Certificate of Acceptance (Air Economizer Controls Acceptance)

California Energy Commission. *Nonresidential Certificate of Acceptance (Air Economizer Controls Acceptance).* 2008.

Acceptance requirements ensure that equipment, controls and systems operate as required by the Standards. The activities specified in these requirements have three aspects:

1. Visual inspection of the equipment and installation
2. Review of the certification requirements
3. Functional tests of the systems and controls

MECH-5A: Air Economizer Controls Acceptance Document
New Construction and Retrofit: All new equipment with air economizer controls must comply. Units with economizers that are installed at the factory and certified with the Commission do not require functional testing but do require construction inspection. Functional tests include:

- Enable economizer, simulate a cooling demand to drive economizer fully open. Verify damper position, all fans/dampers operating correctly.

- Simulate cooling load, disable economizer. Verify damper position, all fans/dampers operating correctly.
- Simulate heating load, enable economizer. Verify damper position, all fans/dampers operating correctly.

General Commissioning Procedure for Economizers

Fromberg, R. Pacific Gas and Electric Company. *General Commissioning Procedure for Economizers*. 2008.

Documents procedures for two fictitious buildings for steps required to fully commission their air system's economizers. The goal of the process is to verify the economizer is working as specified, while looking at opportunities to improve operation.

Draft Final Report, Project 4: Advanced Rooftop Unit

Architectural Energy Corporation. *Draft Final Report, Project 4: Advanced Rooftop Unit*. Prepared for the California Energy Commission. 2008.

This project produced performance guidance for designers and operators on ways to improve efficiency/operations of small package HVAC units. It documents the features of an "advanced RTU" and the laboratory procedures to evaluate such features. Features were sorted into three levels.

Level 1 features (currently available):

- Factory installed economizer
- Direct drive/permanent lubrication
- Differential dry-bulb or enthalpy control, or dewpoint control
- DCV capability
- Compressor lockout on low OAT
- Economizer modulation on low OAT
- Energy Star complaint
- High Efficiency HFC refrigerant (no ozone depletion) will be used
- Continuous supply fan operation during occupied hours and intermittent operation during unoccupied hours will be the default operating modes.
- During unoccupied hours, supply fan will operate for a short period after compressor turns off.
- Unit will use and adjustable expansion control device
- Commercial grade thermostat meeting ASHRAE 90.1 requirements (Dual setpoint, min. 5˚F deadband, continuous fan operation, time-of-day/weekend/holiday programming, temporary override)
- Integrated economizer control
- Sensors with the following characteristics: Accuracy requirements +/- 1˚F, Solid-state electronic humidity elements, Connections designed to prevent misconnection
- Refrigerant line labels if multiple circuits
- Hi-Pressure liquid line port, low-Pressure suction port

- Ports accessible w/o removing panels

Level 2 features (may not be readily available):

- Deadband @ 2˚F or less
- 2- to 5-year factory warranty on economizer parts and labor
- Low-leakage RA damper @ 2%
- Improved-efficiency condenser fan motor (e.g., ECM or PSC)
- Occupancy sensor interface
- CO2 sensor supplied by control mfr
- Min-Outside Air adjustments accessible w/o removing panels
- Permanent sensors, readings displayed at controller
- Controller indicates enabled operating mode including economizer
- Ability to initiate tests of operating modes
- 8-bit (min) digital resolution
- Detect faulty sensors and send notification signals
- Detect faulty economizer and send notification
- Detect and signal evaporator air temperature difference out of range
- Detect and signal refrigerant charge out of range

Level 3 features (advanced features recommended for the future):

- Economizer test standard-industry wide support needed
- Turning vanes for horizontal-discharge units
- Multi- or variable-speed SF interlocked with compressor and OA damper
- Intelligent night flush mode
- Improve installation and O&M literature (especially economizer, DCV and CO2 setup, sensor calibration)
- Ability to override sensors
- Interface with central control system or device
- Data collection and storage

Project also demonstrated that if more advanced RTU fault detection was adopted, then mechanical reliability and durability would increase.

Project test plans for the economizer reliability, unit performance, and field test activities were reviewed and incorporated (where applicable) into the HVAC CASE study lab test procedures.

Premium Ventilation Package Testing – Short Term Monitoring Report

Hart, R. Premium *Ventilation Package Testing – Short Term Monitoring Report*. Prepared for the Bonneville Power Administration. October 12, 2009.

This report documents the field testing procedures that will be used to evaluate the Premium Ventilation measure package.

Several conclusions were drawn from this work in the areas of functionality, energy savings, and recommended improvements. They are as follows:

- Analog type controllers and separate components that need to be field wired on the roof are problematic. Stand-alone combination programmable thermostats with DDC controllers should be the focus for future RTU control retrofit programs.
- The lower cost VSDs with integrated controls do function properly, but care must be taken to install them with the appropriate motors.
- While using VSDs can be cost effective, acceptable ventilation at a lower operating and first cost can be provided by cycling the fan off when not needed for ventilation.
- Acceptable air quality for packaged systems that serve only a few rooms can be maintained with a single CO2 sensor located in the return airstream.
- Controlled ventilation provides much better ventilation than a system with the fan in the automatic setting.

Advanced Building's Core Performance is a prescriptive program to achieve significant, predictable energy savings in new commercial construction. The program describes a set of simple, discrete integrated design strategies and building features. When applied as a package, they result in energy savings of at least 20 to 30% beyond the performance of a building that meets the prescriptive requirements of ASHRAE 90.1 – 2004. Elements of the program can be applied to new commercial projects of all sizes, but the analysis was primarily developed for new buildings and major renovations ranging from 10,000 – 70,000 sf for offices, schools and retail.

The Core Performance Requirements are a set of prescriptive building requirements that exceed the current energy code that lead to quantifiable energy savings. Included in this category of "requirements" are guidelines for economizer performance which are set to ensure savings from the proper performance of outside air economizers.

The following features should be incorporated into economizer design:

- Factory installed
- Fully modulating damper motor (required to allow proper mixed air temperature control)
- Direct modulating actuator with gear driven interconnections and permanently lubricated bushing/bearing on OA and RA dampers
- Proportional damper control
- Coordinated control to ensure that the economizer is only active when there is a call for cooling (utilize a deadband of 2oF or less in a dry bulb temperature application and 2 Btu/lb in an enthalpy application)
- Economizer control by differential dry-bulb, differential enthalpy, or dewpoint/dry bulb temperature control
- Relief air and modulating return air damper
- Verify the minimum OA setpoint by measuring temperature of mixed air, return air and outside air to calculate percentage of OA.

ASHRAE Standard 90.1 – 2007

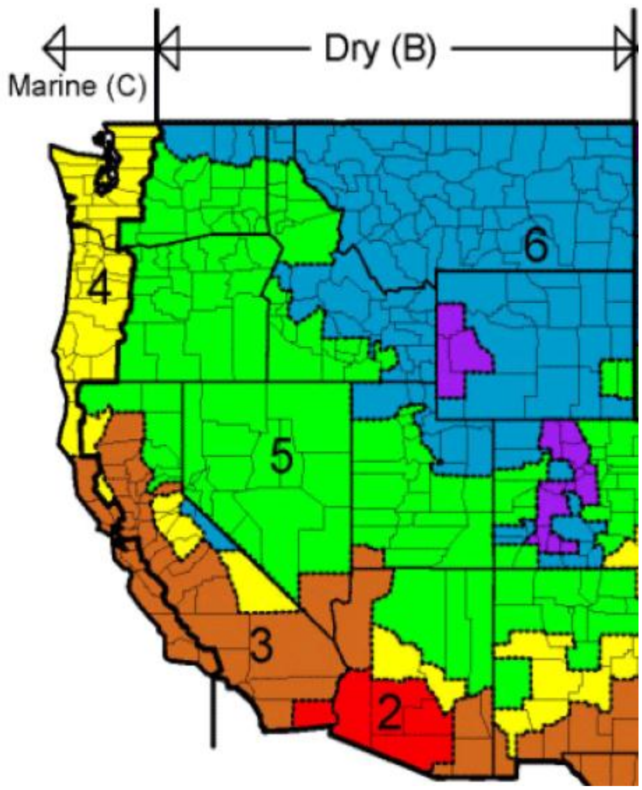
American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. *Energy Standard for Buildings Except Low Rise Residential Buildings (90.1).* 2007.

Section 6.4.3.4.4 – "Dampers. Where outdoor air supply and exhaust air dampers are required by Section 6.4.3.4, they shall have a maximum leakage rate when tested in accordance with AMCA Standard 500 as indicated in Table 6.4.3.4.4."

TABLE 6.4.3.4.4 Maximum Damper Leakage

Climate Zones	Maximum Damper Leakage at 1.0 in. w.g. cfm per ft^2 of damper area	
	Motorized	Nonmotorized
1, 2, 6, 7, 8	4	Not allowed
All others	10	20[a]

[a] Dampers smaller than 24 in. in either dimension may have leakage of 40 cfm/ft^2.



This requirement also applies to air economizer dampers per Section 6.5.1.1.4, which is included under Section 6.5.1.1 Air Economizers.

Section 6.5.1.1.4 – "Dampers. Both return air and outdoor air dampers shall meet the requirements of Section 6.4.3.3.4."

AMCA Standard 500 is titled, “Laboratory Methods of Testing Dampers for Rating.” This standard establishes uniform laboratory test methods for dampers including air leakage, pressure drop, dynamic closure, operational torque, and elevated temperature testing.

From the ASHRAE 90.1-2007 User’s Manual:

- 40 cfm/ft2 for non-motorized dampers that are smaller than 24 inches in either direction in climate zones 3–5. This leakage requirement can be met by standard dampers. (This applies to California’s Imperial County)
- 20 cfm/ft2 for motorized and nonmotorized dampers in climate zones 3–5. This requirement can be met by standard dampers with blade seals. (This applies to all California counties except Imperial County)
- 10 cfm/ft2 for motorized dampers in climate zones 3–5. This will require low-leakage triple-vee-groove dampers with flexible metal compression jamb seals and PVC-coated polyester blade seals. (Polyurethane foam or similar blade seals will not likely provide acceptable performance.) (This applies to all California counties except Imperial County)
- 4 cfm/ft2 for motorized dampers in climate zones 1, 2, and 6–8. This will require an “ultra-low leakage” damper, typically, a damper with airfoil shaped blades, neoprene or vinyl edge seals, and flexible metal compression jamb seals. For larger dampers (those greater than 3 feet or so in width), a vee-groove type blade damper with blade and jamb seals may work. (This applies to California’s Imperial County)

Public Review Draft – Proposed Addendum au to ANSI/ASHRAE/IESNA Standard 90.1 – 2007

American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. *Proposed Addendum to Standard 90.1-2007, Energy Standard for Buildings Except Low Rise Residential Buildings*. January 2010.

Economizer Addendum Justification and Background

Lord, Richard. *Economizer Addendum Justification and Background*. Presented at the ASHRAE Winter Conference. January 24, 2010.

This addendum documents several proposed changes to economizer requirements in section 6.5.1 and 6.3.2.
With increased envelope insulation levels and higher internal plug loads, commercial buildings tend to operate in cooling mode at lower outside air temperatures. This allows for economizers to be used in more applications.

Note - The following climate zones are located within California: 2B, 3B, 3C, 4B, 4C, 5B, and 6B.

Proposed changes:

Note: **Bold** text indicates affected California Climate Zone

- Extend economizer requirements to include climate zones 2a, 3a, and **3b**.
  - No economizer requirement in CZs 1a, 1b

- Decrease the threshold size that requires economizers for comfort cooling from 135,000 Btu/hour and 65,000 Btu/hour to 54,000 Btu/hr for CZs 2a, **2b**, 3a, 4a, 5a, 6a, **3b, 3c, 4b, 4c, 5b**, 5c, **6b**, 7, 8
- Proposed: separate requirements for minimum cooling capacity for which an economizer is required for computer rooms.
  - CZ 1a, 1b, 2a, 3a, 4a: no economizer required
  - CZ **2b**, 5a, 6a, 7, 8: greater or equal to 135,000 Btu/hour
  - CZ **3b, 3c, 4b**, 4c**, 5b**, 5c, **6b:** greater or equal to 65,000 Btu/hour
- Advanced controls for economizers eliminate the need to exempt certain climate zones from the use of integrated economizers.
  - If a unit is rated with an IPLV, IEER, or SEER the minimum cooling efficiency of the HVAC unit must be increased by the percentage shown. If unit is rated with a full load metric like COP or EER – then efficiency must be increased by the percentage shown.

Note: Shaded table row indicates affected California Climate Zone

Climate Zone	Efficiency Improvement
2a	17%
2b	21%
3a	27%
3b	32%
3c	65%
4a	42%
4b	49%
4c	64%
5a	49%
5b	59%
5c	74%
6a	56%
6b	65%
7	72%
8	77%

Appendix A: Prototype DOE-2 Model Descriptions

To estimate the cost effectiveness of the two stage thermostat and the economizer threshold measures, a series of DOE-2 prototype models were developed for a number of building types.

The analysis used a three story building, with 5 zones plus plenum per floor. The building is 164 ft. long by 109 ft. wide, for a total area of 53,630 ft² (17,877 ft² per floor). Floor to floor height is 13 ft. (Note: the same building was used for the economizer threshold analysis, and is based on the Medium Office from the DOE set of reference building models, which are EnergyPlus models.)
The variables that were included in the analysis were:

- Climate zone (3, 6, 9, 12, 14 and 16)
- Window to Wall Ratio (10%, 30% and 60%)
- Occupancy type (high density office, low density office, retail, primary school)
- Economizer operation (For the two stage thermostat simulation: one or two stage thermostat; for the economizer threshold simulation: no economizer or two stage thermostat economizer)

The occupancy types were simulated by varying operating schedules, occupant density, lighting power density, equipment power density, and ventilation rate. Table 1 shows the occupancy, LPD, EPD and ventilation data for each occupancy type. The LPD values for the office and school cases were taken from the 2008 Title 24, Table 5-2 of the Nonres Compliance Manual, Complete Building Method Lighting Power Density Values. Retail buildings cannot use the Complete Building Method, so 1.2 was used as an intermediate values between the 1.6 of retail sales areas and the 0.6 for "corridors, restrooms, stairs and support areas" and 0.6 for Storage. Occupant density values were taken from Table 6-1 of ASHRAE Standard 62.1-2010. The overall OA rates used in the simulation are calculated as cfm/person (cfm/ft^2 x ft^2/person + cfm/person). The occupancy, lighting, and equipment schedules are located in Figure 78 to Figure 86.

	Occupant Density				62.1 Rates		Overall OA Rate
	#/1000 ft²	ft²/person	LPD	EPD	cfm/ft²	cfm/person	cfm/person
High Density Office	30	33.3	0.85	1.5	0.06	5	7
Low Density Office	5	200	0.85	1	0.06	5	17
Retail	15	66.7	1.2	0.5	0.12	7.5	15.5
Primary School	35	28.6	1	0.2	0.12	10	13.4

Figure 77 Parameters Used for the Different Occupancy Types

The occupancy, lighting, and equipment schedules of the prototype models are shown below.

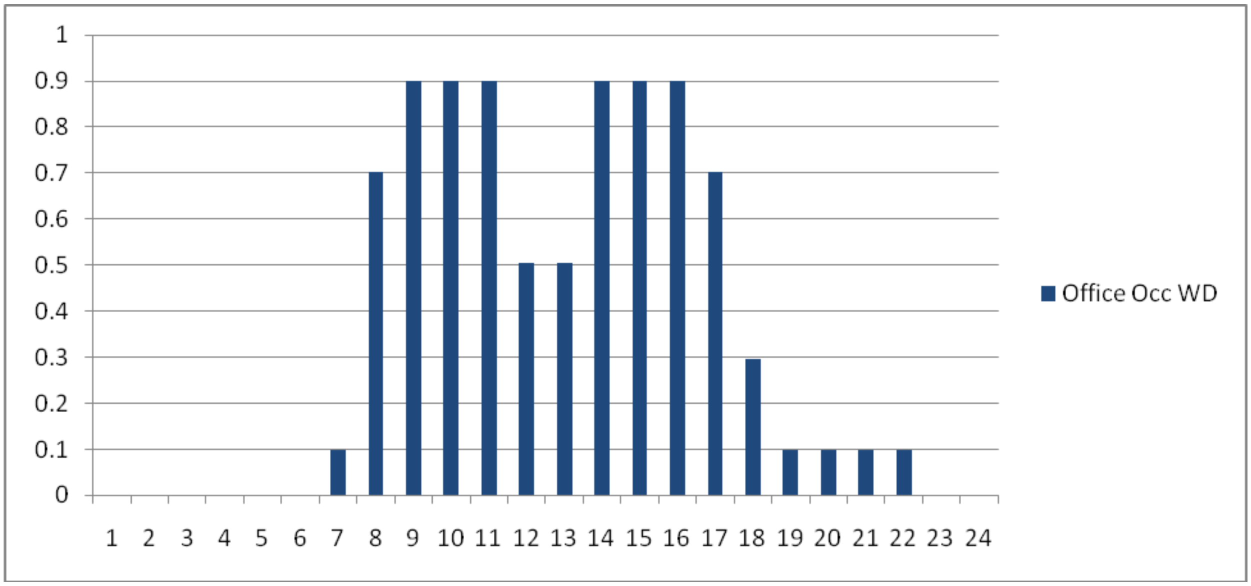


Figure 78 Occupancy Schedules: Office

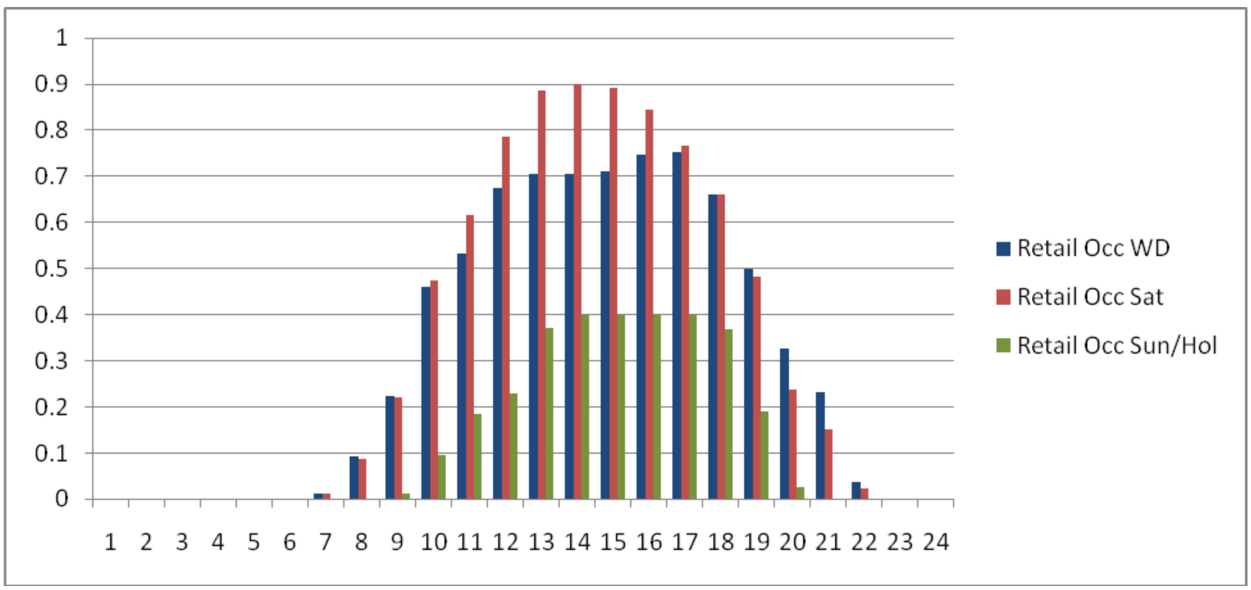


Figure 79 Occupancy Schedules: Retail

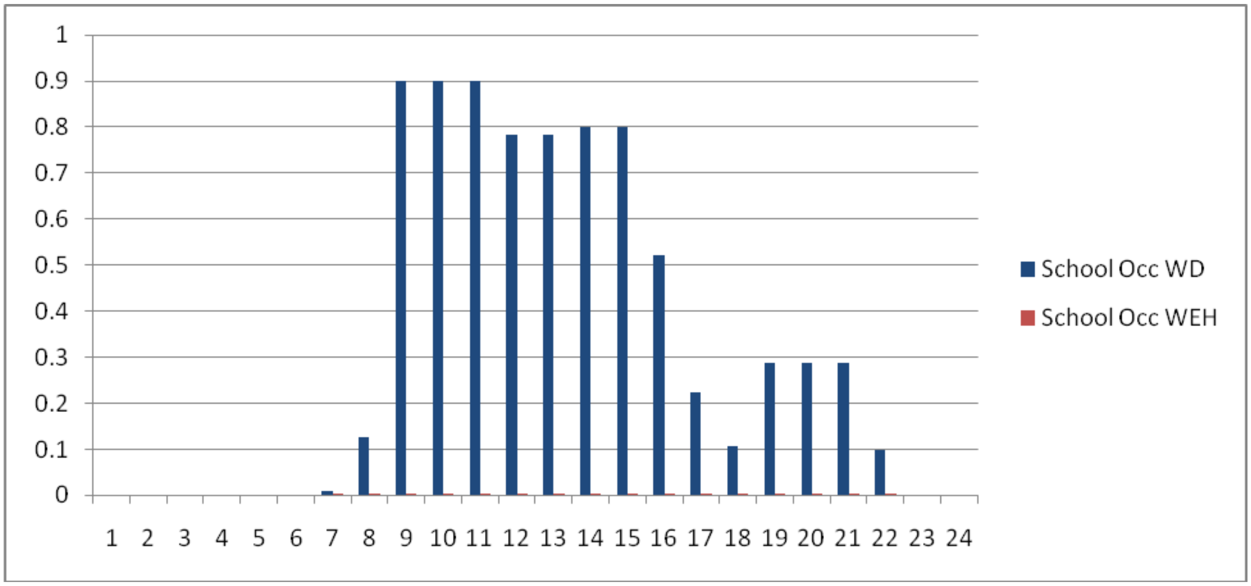


Figure 80 Occupancy Schedules: School

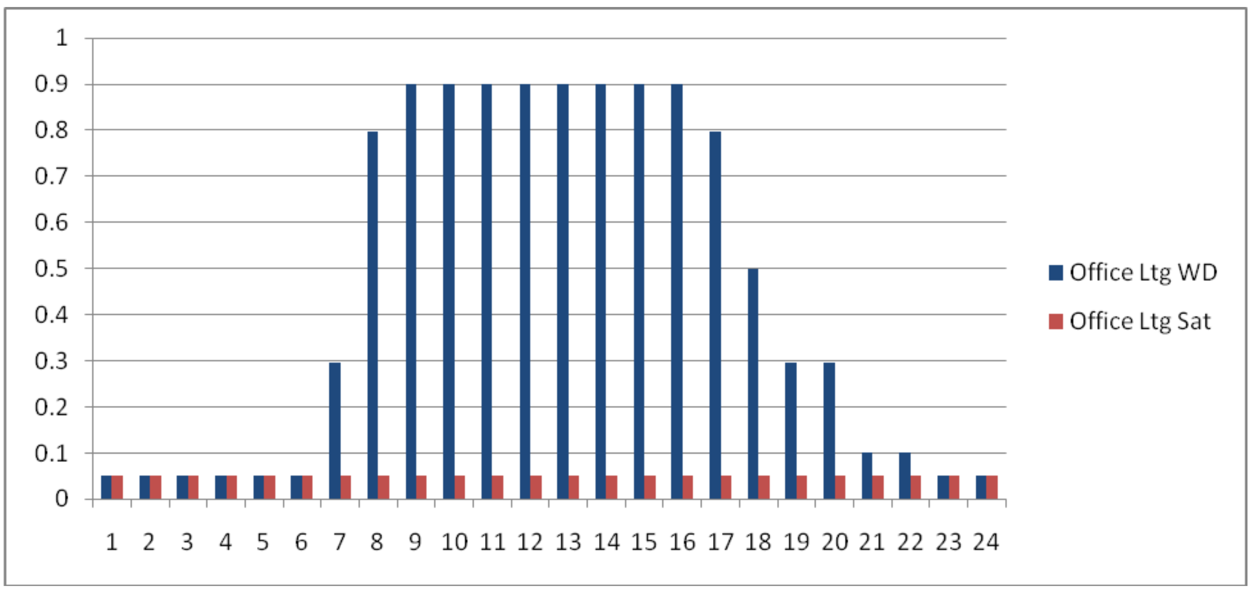


Figure 81 Lighting Schedules: Office

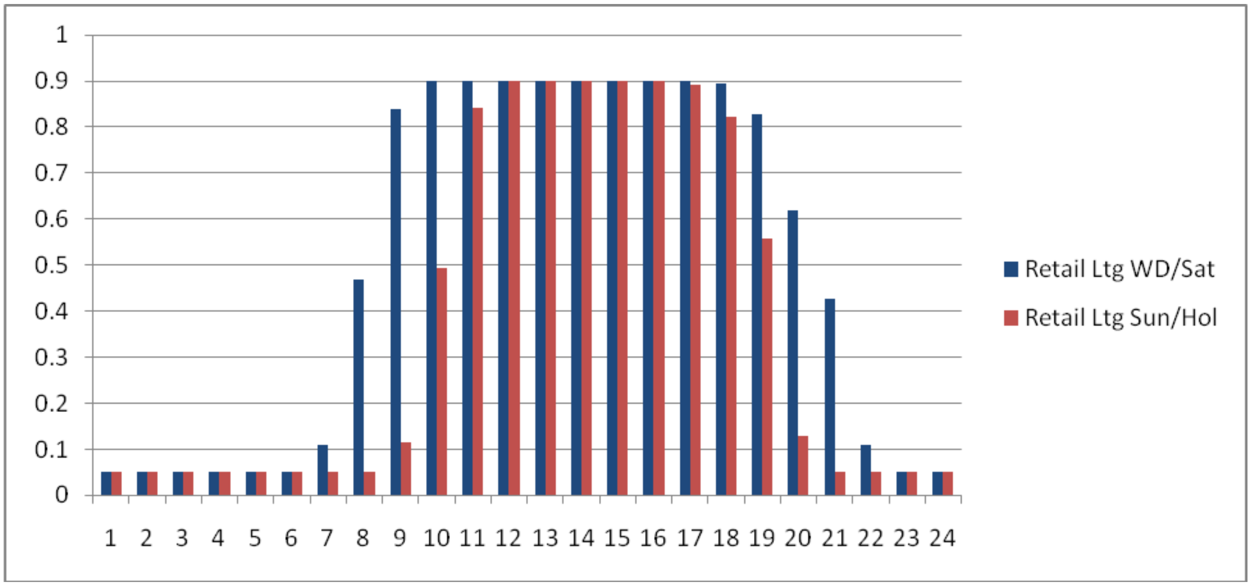


Figure 82 Lighting Schedules: Retail

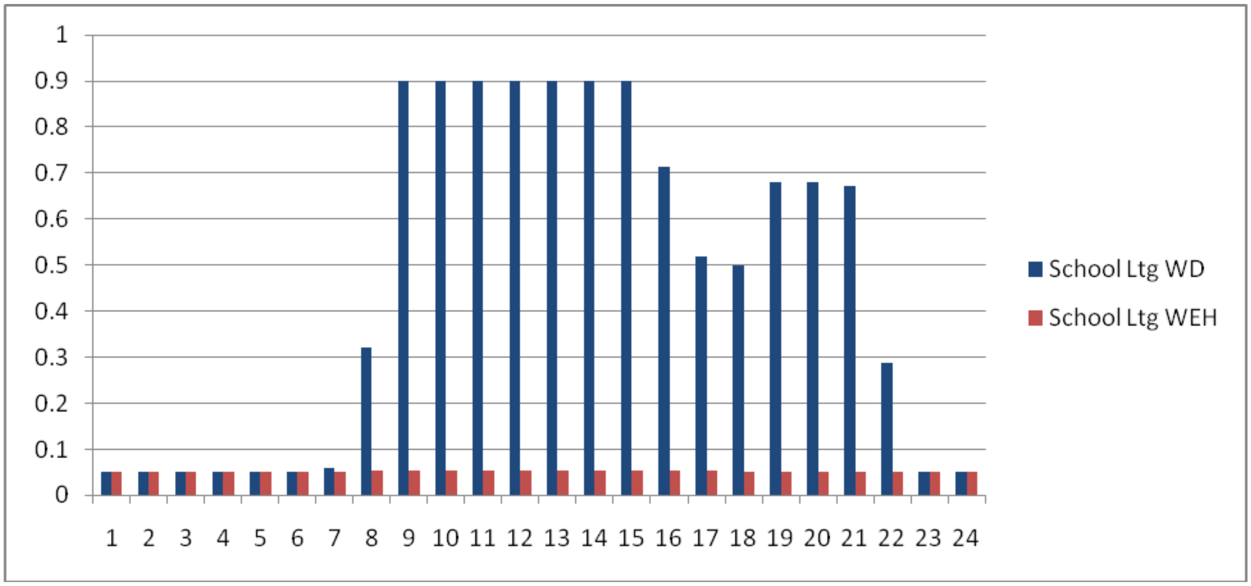


Figure 83 Lighting Schedules: School

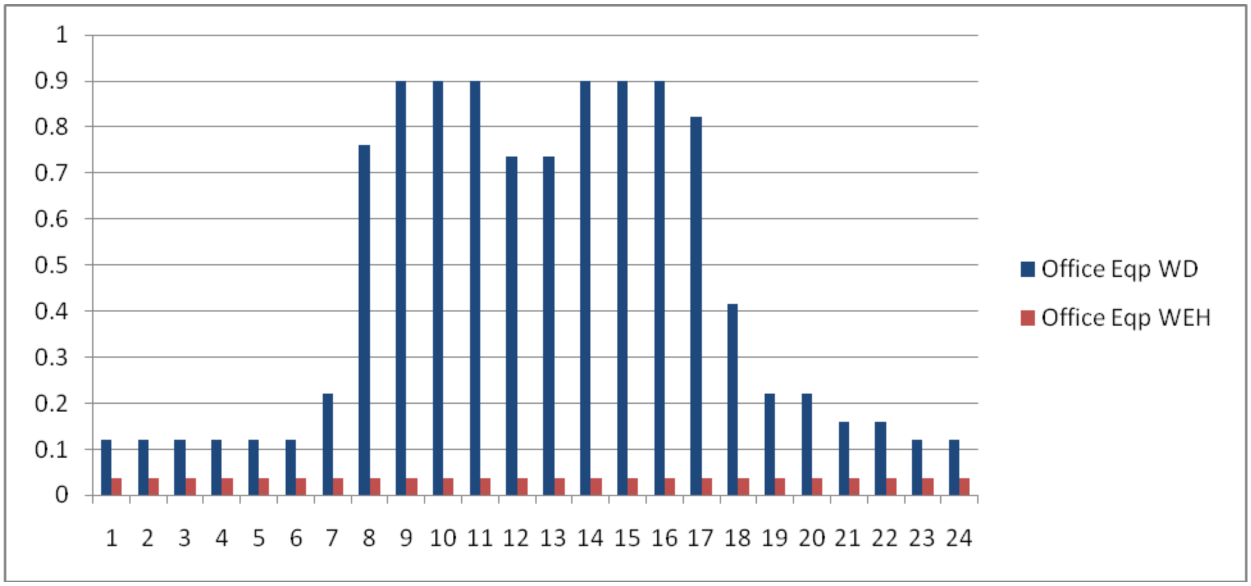


Figure 84 Equipment (Plug Load) Schedules: Office

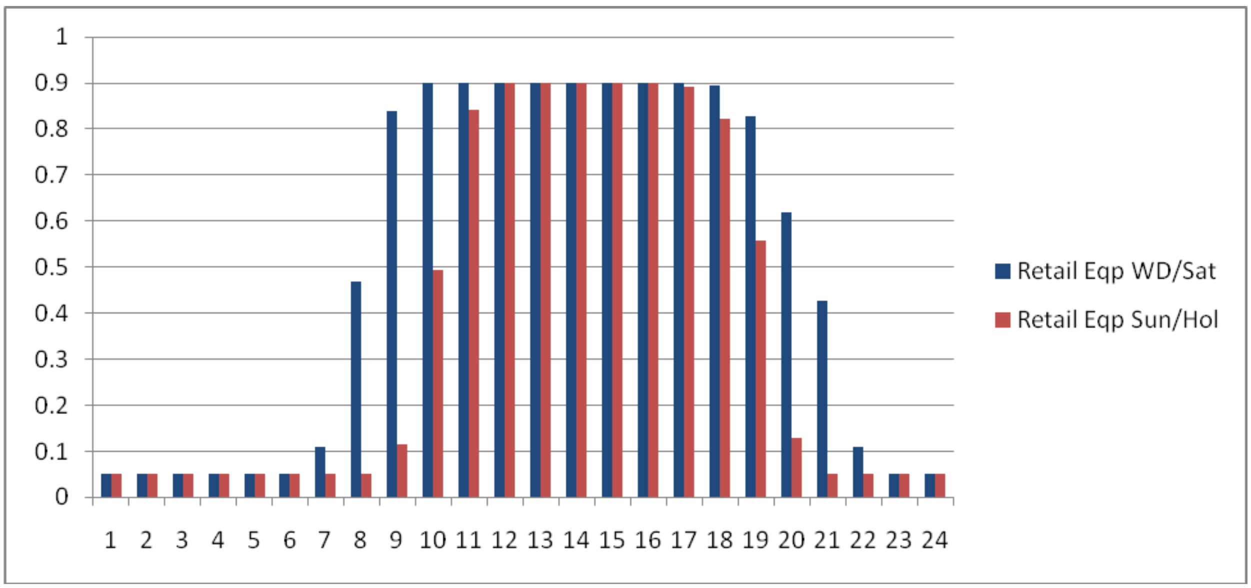


Figure 85 Equipment (Plug Load) Schedules: Retail

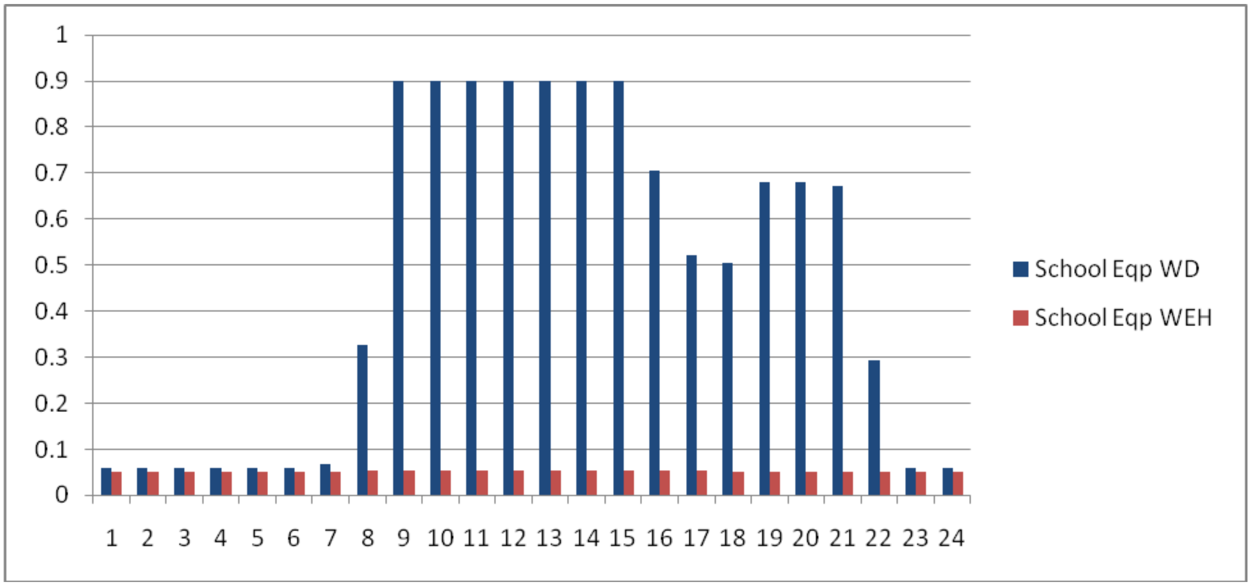


Figure 86 Equipment (Plug Load) Schedules: School

Exterior walls used insulation to provide the climate specific U-values specified in the 2008 Title 24 Table 143-A. Glazing used the U-values and RSHG values from the same table.

Wall construction was:
- 1 in. stucco
- 5/8 in. plywood
- Board insulation (varied by climate zone)
- Framing with batt insulation (R 7.2)
- ½ in. gypsum board

Roof Construction was:
- Built-up roofing
- Board insulation (varied by climate zone)
- 5/8 in. plywood
- Airspace (R 1)
- ½ in. acoustic tile

The building has continuous bands of glazing on each floor. The height of the glazing was varied to get window to wall ratios of 10%, 30% or 60%.

The HVAC systems are packaged VAV systems with hot water reheat provided by a gas boiler. There is one VAV system per floor. Cooling efficiency (EIR) was 0.2552 (SEER 13) with the gas furnace having an HIR of 1.24 (80.6% efficiency). The following DOE-2 keywords were used for the measure case for both the two stage thermostat and the economizer threshold simulation:
- ECONO-LIMIT-T =
  - 69.9˚F High Density Office
  - 73.8˚F Low Density Office
  - 69.4˚F Retail
  - 71.0˚F School

- ECONO-LOCKOUT = NO (Specifies that the economizer can operate simultaneously with the compressor. The economizer will operate to provide as much of the cooling load as possible, with mechanical cooling picking up the remainder of the load. This type of operation is more efficient than a non-integrated economizer, but requires safeguards to ensure proper compressor operation. This control sequence is equivalent to what the California Energy Commission calls an integrated economizer.)
- OA-CONTROL = OA-TEMP
- MAX-OA-FRACTION = 0.7
- COOL-CTRL-RANGE = 0.1

Other significant HVAC system parameters include:

- Fan efficiency: 53%
- Fan static pressure: 1.25 in. w.g.
- System sizing ratio: 1.15
- Heat sizing ratio: 1.25
- Minimum VAV box flow – perimeter zones: 30%
- Minimum VAV box flow – core zones: 40%

Temperature setpoints were 73°F cooling and 70°F heating (occupied) and 77°F cooling and 60°F heating (unoccupied).

The base case for the economizer threshold simulation is no economizer. The base case for the two stage thermostat simulation is identical to the measure case, except for:

- ECONO-LIMIT-T = 55˚F
- ECONO-LOCKOUT = YES (Specifies that the economizer and the compressor cannot operate simultaneously. If the economizer cannot handle the entire cooling load, then mechanical cooling will be enabled and the economizer will return to its minimum position. This control sequence is equivalent to what the California Energy Commission calls a non-integrated economizer.)

The current simulation of economizers in DOE 2.2 with the Packaged Single Zone (PSZ) system has a known problem in that as an hourly simulation it cannot simulate switching between a single stage DX coil cooling operation (that needs to reduce the outside air to avoid comfort problems and coil freezing) and economizer operation where supply air temperature is not an issue. The present routine exaggerates the savings that will accrue from an economizer in a single-stage cooling unit. The energy savings methodology relies on a work around to correct the simulation as described in Appendix K: Modeling Guidance for RTU Economizers.

Appendix B: Energy Savings for FDD

This section provides summaries of the energy savings for the FDD measure.

Fast Food CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	1	88	231	319	$28
Per Prototype Building	40	0	14	933	2,442	3,376	$300
Savings per square foot	0.02	0.00	0.01	0.44	1.16	1.61	$0.14

Fast Food CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	1	88	93	181	$16
Per Prototype Building	43	0	5	933	985	1,918	$171
Savings per square foot	0.02	0.00	0.00	0.44	0.47	0.91	$0.08

Fast Food CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5	0	1	158	117	275	$24
Per Prototype Building	57	0	7	1,670	1,231	2,901	$258
Savings per square foot	0.03	0.00	0.00	0.80	0.59	1.38	$0.12

Fast Food CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5	0	1	145	241	387	$34
Per Prototype Building	53	0	14	1,536	2,551	4,088	$364
Savings per square foot	0.03	0.00	0.01	0.73	1.22	1.95	$0.17

Fast Food CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	6	0	1	171	251	422	$38
Per Prototype Building	61	0	14	1,808	2,650	4,457	$397
Savings per square foot	0.03	0.00	0.01	0.86	1.26	2.12	$0.19

Fast Food CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	3	0	2	80	407	486	$43
Per Prototype Building	31	0	24	840	4,300	5,140	$457
Savings per square foot	0.01	0.00	0.01	0.40	2.05	2.45	$0.22

Grocery CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	6	0	1	141	193	334	$30
Per Prototype Building	1,504	1	272	35,135	48,140	83,275	$7,411
Savings per square foot	0.02	0.00	0.00	0.43	0.59	1.02	$0.09

Grocery CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	6	0	0	145	79	224	$20
Per Prototype Building	1,600	1	109	36,196	19,705	55,901	$4,975
Savings per square foot	0.02	0.00	0.00	0.44	0.24	0.68	$0.06

Grocery CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	9	0	1	246	94	340	$30
Per Prototype Building	2,220	1	126	61,341	23,344	84,685	$7,537
Savings per square foot	0.03	0.00	0.00	0.75	0.28	1.03	$0.09

Grocery CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	8	0	1	229	208	437	$39
Per Prototype Building	2,107	2	280	56,980	51,819	108,799	$9,683
Savings per square foot	0.03	0.00	0.00	0.70	0.63	1.33	$0.12

Grocery CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	10	0	1	290	223	513	$46
Per Prototype Building	2,528	2	298	72,282	55,450	127,731	$11,368
Savings per square foot	0.03	0.00	0.00	0.88	0.68	1.56	$0.14

Grocery CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	6	0	2	171	405	577	$51
Per Prototype Building	1,547	1	551	42,661	101,000	143,661	$12,785
Savings per square foot	0.02	0.00	0.01	0.52	1.23	1.75	$0.16

Large Retail CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	11	0	1	266	153	419	$37
Per Prototype Building	3,201	1	239	76,060	43,770	119,830	$10,664
Savings per square foot	0.02	0.00	0.00	0.55	0.32	0.87	$0.08

Large Retail CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	11	0	0	246	42	288	$26
Per Prototype Building	3,098	1	65	70,303	12,045	82,348	$7,329
Savings per square foot	0.02	0.00	0.00	0.51	0.09	0.60	$0.05

Large Retail CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	13	0	0	317	63	380	$34
Per Prototype Building	3,590	1	95	90,799	17,905	108,704	$9,674
Savings per square foot	0.03	0.00	0.00	0.66	0.13	0.79	$0.07

Large Retail CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	12	0	1	298	188	486	$43
Per Prototype Building	3,352	1	286	85,249	53,694	138,943	$12,366
Savings per square foot	0.02	0.00	0.00	0.62	0.39	1.01	$0.09

Large Retail CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	13	0	1	330	203	533	$47
Per Prototype Building	3,667	1	308	94,470	57,957	152,426	$13,565
Savings per square foot	0.03	0.00	0.00	0.69	0.42	1.11	$0.10

Large Retail CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	9	0	2	235	388	624	$56
Per Prototype Building	2,584	1	598	67,338	111,117	178,455	$15,882
Savings per square foot	0.02	0.00	0.00	0.49	0.81	1.30	$0.12

School CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5	0	1	134	254	387	$34
Per Prototype Building	919	1	245	22,954	43,464	66,418	$5,911
Savings per square foot	0.02	0.00	0.01	0.52	0.99	1.51	$0.13

School CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	7	0	1	154	100	254	$23
Per Prototype Building	1,121	1	95	26,359	17,216	43,575	$3,878
Savings per square foot	0.03	0.00	0.00	0.60	0.39	0.99	$0.09

School CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	10	0	1	294	125	419	$37
Per Prototype Building	1,706	2	115	50,463	21,394	71,857	$6,395
Savings per square foot	0.04	0.00	0.00	1.14	0.49	1.63	$0.14

School CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	9	0	1	260	270	530	$47
Per Prototype Building	1,487	2	251	44,578	46,249	90,827	$8,083
Savings per square foot	0.03	0.00	0.01	1.01	1.05	2.06	$0.18

School CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	10	0	2	314	287	602	$54
Per Prototype Building	1,717	2	266	53,899	49,239	103,137	$9,179
Savings per square foot	0.04	0.00	0.01	1.22	1.12	2.34	$0.21

School CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5	0	3	159	490	648	$58
Per Prototype Building	900	1	461	27,236	83,931	111,166	$9,893
Savings per square foot	0.02	0.00	0.01	0.62	1.90	2.52	$0.22

Small Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	3	0	1	88	203	291	$26
Per Prototype Building	390	0	131	9,991	22,998	32,989	$2,936
Savings per square foot	0.01	0.00	0.00	0.25	0.57	0.82	$0.07

Small Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	1	101	91	192	$17
Per Prototype Building	488	0	57	11,475	10,296	21,771	$1,938
Savings per square foot	0.01	0.00	0.00	0.28	0.25	0.54	$0.05

Small Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	7	0	1	197	103	300	$27
Per Prototype Building	758	1	63	22,399	11,703	34,102	$3,035
Savings per square foot	0.02	0.00	0.00	0.55	0.29	0.84	$0.08

Small Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	6	0	1	176	209	385	$34
Per Prototype Building	673	1	129	19,990	23,702	43,692	$3,888
Savings per square foot	0.02	0.00	0.00	0.49	0.59	1.08	$0.10

Small Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	8	0	1	237	222	459	$41
Per Prototype Building	862	1	136	26,944	25,150	52,093	$4,636
Savings per square foot	0.02	0.00	0.00	0.67	0.62	1.29	$0.11

Small Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	2	122	386	508	$45
Per Prototype Building	436	1	240	13,828	43,823	57,651	$5,131
Savings per square foot	0.01	0.00	0.01	0.34	1.08	1.43	$0.13

Small Retail CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	12	0	1	289	208	497	$44
Per Prototype Building	301	0	28	7,132	5,124	12,256	$1,091
Savings per square foot	0.04	0.00	0.00	0.88	0.63	1.50	$0.13

Small Retail CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	12	0	0	263	69	333	$30
Per Prototype Building	288	0	9	6,493	1,711	8,203	$730
Savings per square foot	0.04	0.00	0.00	0.80	0.21	1.01	$0.09

Small Retail CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	12	0	0	302	92	394	$35
Per Prototype Building	300	0	12	7,462	2,266	9,727	$866
Savings per square foot	0.04	0.00	0.00	0.92	0.28	1.19	$0.11

Small Retail CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	11	0	1	285	239	524	$47
Per Prototype Building	282	0	31	7,036	5,891	12,927	$1,150
Savings per square foot	0.03	0.00	0.00	0.86	0.72	1.59	$0.14

Small Retail CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	12	0	1	294	261	555	$49
Per Prototype Building	286	0	34	7,259	6,429	13,688	$1,218
Savings per square foot	0.04	0.00	0.00	0.89	0.79	1.68	$0.15

Small Retail CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	9	0	2	224	455	680	$60
Per Prototype Building	220	0	61	5,537	11,230	16,767	$1,492
Savings per square foot	0.03	0.00	0.01	0.68	1.38	2.06	$0.18

Large Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	2	0	0	58	76	134	$12
Per Prototype Building	1,016	1	184	24,213	32,043	56,256	$5,007
Savings per square foot	0.01	0.00	0.00	0.22	0.29	0.50	$0.04

Large Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	3	0	0	61	36	98	$9
Per Prototype Building	1,156	1	85	25,836	15,268	41,103	$3,658
Savings per square foot	0.01	0.00	0.00	0.23	0.14	0.37	$0.03

Large Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	0	115	40	154	$14
Per Prototype Building	1,701	2	91	48,190	16,712	64,902	$5,776
Savings per square foot	0.02	0.00	0.00	0.43	0.15	0.58	$0.05

Large Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	0	105	73	178	$16
Per Prototype Building	1,590	2	168	44,173	30,615	74,788	$6,656
Savings per square foot	0.01	0.00	0.00	0.39	0.27	0.67	$0.06

Large Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	4	0	0	122	75	197	$18
Per Prototype Building	1,845	2	171	51,478	31,473	82,951	$7,382
Savings per square foot	0.02	0.00	0.00	0.46	0.28	0.74	$0.07

Large Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	2	0	1	66	116	182	$16
Per Prototype Building	970	1	272	27,844	48,888	76,732	$6,829
Savings per square foot	0.01	0.00	0.00	0.25	0.44	0.68	$0.06

Appendix C: Energy Savings for Occupancy Sensors

This section provides summaries of the energy savings for the occupancy sensor measure.

Large Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	8,309	51	233,010	8,378	241,388	249,766	$22,228
Per Prototype Building	15,620	96	438,059	15,750	453,809	469,560	$41,789
Savings per square foot	42	0.26	1,168	42	1,210	1,252	111

Large Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	7,882	12	221,040	1,892	222,931	224,823	$20,009
Per Prototype Building	14,818	22	415,554	3,556	419,111	422,667	$37,616
Savings per square foot	40	0.06	1,108	9	1,118	1,127	100

Large Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	6,706	15	188,051	2,432	190,483	192,915	$17,169
Per Prototype Building	12,606	28	353,535	4,573	358,108	362,681	$32,277
Savings per square foot	34	0.07	943	12	955	967	86

Large Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5,979	61	167,682	9,999	177,681	187,680	$16,703
Per Prototype Building	11,241	115	315,242	18,799	334,041	352,839	$31,402
Savings per square foot	30	0.31	841	50	891	941	84

Large Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5,392	53	151,211	8,648	159,859	168,507	$14,997
Per Prototype Building	10,137	100	284,276	16,258	300,534	316,793	$28,194
Savings per square foot	27	0.27	758	43	801	845	75

Large Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	2,589	7	72,613	1,081	73,694	74,775	$6,655
Per Prototype Building	4,868	12	136,512	2,032	138,544	140,576	$12,511
Savings per square foot	13	0.03	364	5	369	375	33

School CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	100,582	506	2,820,715	82,705	2,903,420	2,986,125	$265,756
Per Prototype Building	189,094	952	5,302,945	155,485	5,458,430	5,613,915	$499,620
Savings per square foot	504	2.54	14,141	415	14,556	14,970	1,332

School CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	87,924	44	2,465,734	7,192	2,472,925	2,480,117	$220,722
Per Prototype Building	165,297	83	4,635,579	13,520	4,649,100	4,662,620	$414,958
Savings per square foot	441	0.22	12,362	36	12,398	12,434	1,107

School CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	77,687	198	2,178,661	32,363	2,211,024	2,243,387	$199,654
Per Prototype Building	146,052	372	4,095,883	60,842	4,156,726	4,217,568	$375,350
Savings per square foot	389	0.99	10,922	162	11,085	11,247	1,001

School CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	74,055	704	2,076,797	115,068	2,191,865	2,306,933	$205,310
Per Prototype Building	139,223	1,324	3,904,379	216,328	4,120,706	4,337,034	$385,982
Savings per square foot	371	3.53	10,412	577	10,989	11,565	1,029

School CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	73,373	638	2,057,659	104,280	2,161,939	2,266,219	$201,686
Per Prototype Building	137,940	1,200	3,868,399	196,047	4,064,446	4,260,492	$379,170
Savings per square foot	368	3.20	10,316	523	10,839	11,361	1,011

School CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	35,751	837	1,002,592	136,643	1,139,235	1,275,878	$113,549
Per Prototype Building	67,211	1,573	1,884,872	256,889	2,141,761	2,398,650	$213,472
Savings per square foot	179	4.19	5,026	685	5,711	6,396	569

Small Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	570	4	15,974	734	16,708	17,442	$1,552
Per Prototype Building	1,071	8	30,032	1,380	31,411	32,791	$2,918
Savings per square foot	2.86	0.02	80.08	3.68	83.76	87.44	$7.78

Small Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	581	1	16,293	116	16,409	16,524	$1,471
Per Prototype Building	1,092	1	30,630	218	30,848	31,066	$2,765
Savings per square foot	3	0.00	82	1	82	83	7

Small Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	486	1	13,634	193	13,827	14,020	$1,248
Per Prototype Building	914	2	25,631	363	25,994	26,357	$2,346
Savings per square foot	2	0.01	68	1	69	70	6

Small Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	401	4	11,260	579	11,839	12,418	$1,105
Per Prototype Building	755	7	21,168	1,089	22,257	23,346	$2,078
Savings per square foot	2	0.02	56	3	59	62	6

Small Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	373	4	10,451	695	11,146	11,841	$1,054
Per Prototype Building	701	8	19,647	1,307	20,954	22,261	$1,981
Savings per square foot	2	0.02	52	3	56	59	5

Small Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	197	0	5,537	77	5,614	5,691	$507
Per Prototype Building	371	1	10,410	145	10,555	10,700	$952
Savings per square foot	1	0.00	28	0	28	29	3

Appendix D: Energy Savings for Two-Stage Thermostat

This section provides summaries of the energy savings for the two-stage thermostat measure.

School CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	100	0	-1	1,881	-173	1,708	$152
Per Prototype Building	15,004	0	-159	281,537	-25,829	255,709	$22,757
Savings per square foot	0.28	0.00	0.00	5.25	-0.48	4.77	$0.42
School CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	47	0	-1	766	-109	656	$58
Per Prototype Building	7,660	0	-104	124,468	-17,799	106,669	$9,493
Savings per square foot	0.14	0.00	0.00	2.32	-0.33	1.99	$0.18
School CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	48	0	0	879	-62	818	$73
Per Prototype Building	10,083	0	-77	183,194	-12,858	170,337	$15,159
Savings per square foot	0.19	0.00	0.00	3.42	-0.24	3.18	$0.28
School CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	58	0	0	1,074	-81	993	$88
Per Prototype Building	10,216	0	-87	188,568	-14,244	174,323	$15,514
Savings per square foot	0.19	0.00	0.00	3.52	-0.27	3.25	$0.29

School CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	42	0	0	758	-54	704	$63
Per Prototype Building	7,568	0	-58	137,447	-9,846	127,600	$11,356
Savings per square foot	0.14	0.00	0.00	2.56	-0.18	2.38	$0.21

School CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	39	0	0	711	-38	674	$60
Per Prototype Building	5,218	0	-32	95,169	-5,024	90,146	$8,023
Savings per square foot	0.10	0.00	0.00	1.77	-0.09	1.68	$0.15

LD Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	198	0	-3	2,495	-492	2,003	$178
Per Prototype Building	21,326	0	-437	373,455	-73,596	299,859	$26,686
Savings per square foot	0.40	0.00	-0.01	6.96	-1.37	5.59	$0.50

LD Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	5	0	-2	-586	-271	-857	-$76
Per Prototype Building	622	-5	-248	-95,236	-44,127	-139,362	-$12,403
Savings per square foot	0.01	0.00	0.00	-1.78	-0.82	-2.60	-$0.23

LD Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	82	0	-1	1,077	-205	872	$78
Per Prototype Building	12,107	0	-246	224,274	-42,624	181,650	$16,166
Savings per square foot	0.23	0.00	0.00	4.18	-0.79	3.39	$0.30
LD Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	119	0	-2	1,681	-285	1,397	$124
Per Prototype Building	15,694	0	-291	295,099	-49,969	245,130	$21,816
Savings per square foot	0.29	0.00	-0.01	5.50	-0.93	4.57	$0.41
LD Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	95	0	-1	1,258	-185	1,074	$96
Per Prototype Building	12,343	0	-190	228,102	-33,460	194,642	$17,323
Savings per square foot	0.23	0.00	0.00	4.25	-0.62	3.63	$0.32
LD Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	77	0	-1	1,073	-138	935	$83
Per Prototype Building	7,892	0	-116	143,567	-18,474	125,094	$11,133
Savings per square foot	0.15	0.00	0.00	2.68	-0.34	2.33	$0.21

Retail CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	182	0	-3	3,218	-483	2,735	$243
Per Prototype Building	25,106	0	-428	481,735	-72,356	409,379	$36,433
Savings per square foot	0.47	0.00	-0.01	8.98	-1.35	7.63	$0.68
Retail CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	87	0	-2	1,209	-297	912	$81
Per Prototype Building	11,053	0	-274	196,559	-48,304	148,256	$13,194
Savings per square foot	0.21	0.00	-0.01	3.66	-0.90	2.76	$0.25
Retail CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	97	0	-1	1,547	-213	1,334	$119
Per Prototype Building	17,390	0	-253	322,311	-44,468	277,843	$24,727
Savings per square foot	0.32	0.00	0.00	6.01	-0.83	5.18	$0.46
Retail CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	114	0	-2	1,916	-285	1,631	$145
Per Prototype Building	17,887	0	-286	336,271	-49,959	286,312	$25,481
Savings per square foot	0.33	0.00	-0.01	6.27	-0.93	5.34	$0.48

Retail CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	92	0	-1	1,626	-197	1,430	$127
Per Prototype Building	16,078	0	-201	294,753	-35,621	259,132	$23,062
Savings per square foot	0.30	0.00	0.00	5.50	-0.66	4.83	$0.43
Retail CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	69	0	-1	1,146	-111	1,035	$92
Per Prototype Building	8,303	0	-92	153,356	-14,842	138,514	$12,327
Savings per square foot	0.15	0.00	0.00	2.86	-0.28	2.58	$0.23

HD Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	211	0	-2	4,084	-424	3,660	$326
Per Prototype Building	35,058	0	-411	677,442	-70,351	607,091	$54,029
Savings per square foot	0.65	0.00	-0.01	12.63	-1.31	11.32	$1.01

HD Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	106	0	-2	1,824	-266	1,559	$139
Per Prototype Building	17,123	0	-244	294,191	-42,825	251,367	$22,371
Savings per square foot	0.32	0.00	0.00	5.48	-0.80	4.69	$0.42

HD Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	101	0	-1	1,864	-157	1,707	$152
Per Prototype Building	23,399	0	-209	431,481	-36,293	395,189	$35,171
Savings per square foot	0.44	0.00	0.00	8.04	-0.68	7.37	$0.66

HD Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	120	0	-1	2,244	-216	2,028	$181
Per Prototype Building	24,857	0	-257	465,060	-44,694	420,366	$37,411
Savings per square foot	0.46	0.00	0.00	8.67	-0.83	7.84	$0.70

HD Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	86	0	-1	1,581	-131	1,450	$129
Per Prototype Building	17,520	0	-150	322,743	-26,726	296,017	$26,345
Savings per square foot	0.33	0.00	0.00	6.02	-0.50	5.52	$0.49

HD Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	76	0	-1	1,399	-88	1,311	$117
Per Prototype Building	11,909	0	-89	219,512	-13,822	205,690	$18,306
Savings per square foot	0.22	0.00	0.00	4.09	-0.26	3.83	$0.34

Appendix E: Energy Savings for Economizer Size

This section provides summaries of the energy savings for reducing the economizer size threshold.

School CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	178	0	0	3,466	-30	3,436	$306
Per Prototype Building	26,604	0	-29	518,838	-4,468	514,370	$45,777
Savings per square foot	0.50	0.00	0.00	9.67	-0.08	9.59	$0.85
School CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	91	0	0	1,558	-29	1,529	$136
Per Prototype Building	14,864	0	-27	253,229	-4,717	248,512	$22,117
Savings per square foot	0.28	0.00	0.00	4.72	-0.09	4.63	$0.41
School CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	76	0	0	1,364	-21	1,343	$119
Per Prototype Building	15,807	0	-26	284,114	-4,409	279,705	$24,893
Savings per square foot	0.29	0.00	0.00	5.30	-0.08	5.21	$0.46
School CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	105	0	0	1,914	-27	1,887	$168
Per Prototype Building	18,428	0	-28	336,003	-4,727	331,276	$29,482
Savings per square foot	0.34	0.00	0.00	6.26	-0.09	6.18	$0.55

School CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	95	0	0	1,685	-27	1,658	$148
Per Prototype Building	17,243	0	-27	305,496	-4,925	300,571	$26,750
Savings per square foot	0.32	0.00	0.00	5.70	-0.09	5.60	$0.50
School CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	191	0	-2	3,205	-299	2,906	$259
Per Prototype Building	25,531	0	-221	428,782	-39,983	388,799	$34,602
Savings per square foot	0.48	0.00	0.00	7.99	-0.75	7.25	$0.65
LD Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	367	0	-1	5,006	-156	4,850	$432
Per Prototype Building	39,513	0	-140	749,309	-23,336	725,973	$64,609
Savings per square foot	0.74	0.00	0.00	13.97	-0.44	13.54	$1.20
LD Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	131	0	-1	1,227	-89	1,138	$101
Per Prototype Building	14,813	-1	-84	199,440	-14,511	184,929	$16,458
Savings per square foot	0.28	0.00	0.00	3.72	-0.27	3.45	$0.31

LD Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	164	0	0	2,129	-72	2,057	$183
Per Prototype Building	24,207	0	-88	443,608	-15,102	428,507	$38,136
Savings per square foot	0.45	0.00	0.00	8.27	-0.28	7.99	$0.71
LD Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	272	0	-1	3,824	-110	3,714	$331
Per Prototype Building	35,888	0	-112	671,139	-19,299	651,840	$58,012
Savings per square foot	0.67	0.00	0.00	12.51	-0.36	12.15	$1.08
LD Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	242	0	0	3,144	-87	3,057	$272
Per Prototype Building	31,353	0	-88	569,953	-15,829	554,124	$49,315
Savings per square foot	0.58	0.00	0.00	10.63	-0.30	10.33	$0.92
LD Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	418	0	-4	5,605	-690	4,915	$437
Per Prototype Building	42,696	0	-512	749,828	-92,335	657,493	$58,515
Savings per square foot	0.80	0.00	-0.01	13.98	-1.72	12.26	$1.09

Retail CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	234	0	-1	4,197	-143	4,055	$361
Per Prototype Building	32,325	0	-126	628,221	-21,335	606,886	$54,011
Savings per square foot	0.60	0.00	0.00	11.71	-0.40	11.31	$1.01
Retail CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	139	0	-1	1,994	-96	1,898	$169
Per Prototype Building	17,719	0	-89	324,083	-15,554	308,530	$27,458
Savings per square foot	0.33	0.00	0.00	6.04	-0.29	5.75	$0.51
Retail CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	121	0	0	1,912	-70	1,842	$164
Per Prototype Building	21,653	0	-83	398,331	-14,484	383,847	$34,161
Savings per square foot	0.40	0.00	0.00	7.43	-0.27	7.16	$0.64
Retail CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	157	0	-1	2,621	-104	2,517	$224
Per Prototype Building	24,641	0	-102	460,091	-18,269	441,823	$39,321
Savings per square foot	0.46	0.00	0.00	8.58	-0.34	8.24	$0.73

Retail CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	132	0	0	2,303	-87	2,216	$197
Per Prototype Building	23,009	0	-88	417,532	-15,790	401,742	$35,754
Savings per square foot	0.43	0.00	0.00	7.78	-0.29	7.49	$0.67

Retail CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	123	0	-2	1,900	-277	1,623	$144
Per Prototype Building	14,906	0	-205	254,150	-37,026	217,124	$19,323
Savings per square foot	0.28	0.00	0.00	4.74	-0.69	4.05	$0.36

HD Office CZ3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	316	0	-1	6,159	-90	6,069	$540
Per Prototype Building	52,391	0	-90	1,021,546	-14,880	1,006,665	$89,590
Savings per square foot	0.98	0.00	0.00	19.05	-0.28	18.77	$1.67

HD Office CZ6	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	178	0	0	3,202	-67	3,135	$279
Per Prototype Building	28,744	0	-62	516,440	-10,849	505,591	$44,996
Savings per square foot	0.54	0.00	0.00	9.63	-0.20	9.43	$0.84

HD Office CZ9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	141	0	0	2,581	-42	2,540	$226
Per Prototype Building	32,696	0	-56	597,622	-9,629	587,992	$52,329
Savings per square foot	0.61	0.00	0.00	11.14	-0.18	10.96	$0.98

HD Office CZ12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	198	0	0	3,687	-61	3,626	$323
Per Prototype Building	41,127	0	-73	764,125	-12,635	751,491	$66,880
Savings per square foot	0.77	0.00	0.00	14.25	-0.24	14.01	$1.25

HD Office CZ14	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	163	0	0	2,955	-51	2,903	$258
Per Prototype Building	33,362	0	-59	603,065	-10,490	592,575	$52,737
Savings per square foot	0.62	0.00	0.00	11.24	-0.20	11.05	$0.98

HD Office CZ16	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings (kbtu)	TDV Gas Savings (kbtu)	TDV Total Savings (kBtu)	TDV Total Savings ($)
Per Ton Cooling	254	0	0	4,485	-56	4,428	$394
Per Prototype Building	39,857	0	-52	703,442	-8,849	694,593	$61,817
Savings per square foot	0.74	0.00	0.00	13.12	-0.16	12.95	$1.15

Appendix F: Economizer Reliability Lab Testing

This section provides a summary of the lab testing.

The original goal of this project was to develop a test method, certification protocol, and code requirement of reliable code-compliant economizers to ensure that new economizers on light commercial unitary HVAC units meet specific performance standards. This would include requirements such as:

- Manufacturers shall comply with the code requirement and attain certification for roof top units (RTUs) sold in California, from a third-party test lab (e.g. Intertek is one option).
- 1 of every 1000 units sold in California shall be tested.
- These models shall be recorded in the CEC Appliance Database.

The feasibility of third-party testing was evaluated by executing example tests at an HVAC test facility. Lab testing was conducted at Intertek's HVAC test facility in Dallas, Texas in late October 2010. This facility has a number of psychrometric chambers configured to provide specific indoor and outdoor test conditions.

A light commercial RTU was donated for the testing by a major manufacturer. This is a 5-ton (59,500 Btuh) unit with cooling efficiency of 15.5 SEER, 12.8 EER. The outdoor air and return air dampers are modulated by a direct drive actuator.

The following tests were conducted:

1. Temperature sensor calibration
2. Economizer damper cycles
3. Damper leakage
4. Proper integration between economizer and compressor
5. Economizer high limit control and deadband

Temperature Sensor Calibration

Purpose of Test:

The purpose of this test is to assess the accuracy of the RTU's onboard temperature sensors. It is preferable that temperature sensors have an accuracy of ± 1.0°F. Maintaining a tight sensor accuracy will result in better control of outside air and the unit in general. This accuracy is exclusive of any inaccuracy that may be added by the analog to digital conversion. To some extent this test indirectly addresses the issue of sensor placement. Sensors must be appropriately placed to accurately measure average temperatures and avoid solar load.

Test Plans:

The initial test plan and the preferred process is to immerse the RTU sensors into a temperature regulated drywell calibrator and witness the sensor response over a range of temperatures, thus measuring the accuracy of each sensor. This includes the following sensors: supply air temperature (SAT), return air temperature (RAT), and outside air temperature (OAT).

Actual Test:

Using a temperature regulated drywell calibrator must be done before the sensor is installed and connected in the RTU because access to the temperature sensor and its output can be very difficult or impossible on many RTUs, including the unit under test. Some units, including this one under test, provide an LCD showing the temperature sensor output; however it is usually an integer and thus low resolution (i.e. ±0.5˚F on the display alone).

The actual test thus diverged from the test plan. The actual test involved assessing the accuracy of the RTU's onboard temperature sensors by comparing with reference temperature sensors. The reference temperature sensors are Type-T copper thermocouples with a standard limit of error of 1.0˚C (1.8˚F). These were arranged in a 14-point (2 x 7) grid across the outside air intake just upstream of the outside air dampers. This arrangement provides the average OAT of the airflow entering the unit. The thermocouple grid for the OAT sensor test is partially shown below in Figure 87. The setup for the supply air temperature sensor and the return air temperature sensor is similar, using reference temperature sensors arranged in a 9-point (3 x 3) grid across the supply air plenum and the return air plenum.

Figure 87 Thermocouple grid monitoring the outside air temperature (OAT) with the RTU's OAT sensor shown in the lower right

A second reference temperature arrangement was installed for redundancy and improved accuracy. These sensors were RTDs, or Resistance Temperature Detectors. RTDs have a higher sensitivity and accuracy (0.27˚F @ 32˚F) over thermocouples, but a longer response time. This is important for tests with quickly changing temperatures, but not an issue during this temperature sensor calibration test with stable temperatures. The air intake for the RTD measuring the OAT is shown below in Figure 88.

Figure 88 RTD air intake used for monitoring the outside air temperature (OAT)

The test proceeded as follows:

Table 4: Temperature Sensor Calibration Test

1	Command the RTU into mechanical cooling mode at 80°F indoor, 95°F outdoor (+/- 2°F)
2	Allow the RTU to achieve steady state operation including stable SAT
3	Record time it takes to achieve steady state operation
4	Record SAT, RAT, OAT from RTU and reference temperature sensors every minute (averaged over 1 minute) for a total of 10 readings
5	Command the RTU into full economizing mode with no mechanical cooling at 80°F indoor, 65°F outdoor (+/- 2°F)
6	Allow the RTU to achieve steady state operation including stable SAT
7	Record time it takes to achieve steady state operation
8	Record SAT, RAT, OAT from RTU and reference temperature sensors every minute (averaged over 1 minute) for a total of 10 readings
9	Test passes if all 20 RTU readings from SAT, RAT, OAT are within 1.0°F of reference temperature readings

Conclusions:

Access to the temperature sensor output can be intrusive or impossible on some RTUs. On some units, the sensors are wired directly to control boards. Some units provide an LED readout of the temperature sensor readings, which is usually an integer and thus low resolution (i.e. ±0.5˚F).

Recommendation:

Do not require laboratory testing of RTUs for this purpose. Require product specification sheet showing sensor accuracy, hysteresis, and drift as a part of economizer reliability certification. Hysteresis and drift were not included in this lab testing scope of work but they are important characteristics of HVAC temperature sensors.

It is generally agreed that a laboratory environment is preferred over the production environment to verify temperature sensor characteristics such as calibration, hysteresis, and drift. Laboratory environments with psychrometric rooms are not needed to functionally test temperature sensors. The preferred process is to immerse the sensor into a temperature regulated drywell calibrator and witness the sensor response over a range of temperatures. This must be done before the sensor is installed and connected in the RTU because access to the temperature sensor and its output can be very difficult or impossible on many RTUs. Some units provide an LCD display of the temperature sensor output, however it is usually an integer and thus low resolution (i.e. ±0.5˚F on the display alone).

HVAC manufacturers qualify their vendors and vendor supplied components during RTU product development. Vendors are required to notify the OEMs if they modify the components. Temperature sensor vendors already produce a calibration curve for their sensors. They can provide this toward the economizer reliability certification. It is unrealistic to expect this type of testing to occur for every unit in a production environment especially considering the likely measurement bias from the measurement instruments and/or operators. It is also unrealistic to expect this testing to occur at a third party lab as the sensor leads would need to be cut, then reattached after the calibration exercise. In addition, testing at a third party would be rather expensive especially considering this is one of the least important elements of the economizer reliability certification.

Economizer Damper Cycles

Purpose of Test:

The purpose of this test is to assess the reliability of the economizer damper assembly by modulating the damper open and closed through many cycles.

Test Plans:

The initial test plan is as follows:

Table 5; Initial Economizer Damper Assembly Cycling Test

1	Configure or program the economizer damper and actuator assembly such that it modulates continuously between fully open/closed/open, etc.
2	The time interval or rate of actuation should be similar to the unit's normal cycle
3	Command the actuator to begin cycling the damper
4	Allow damper to continue cycling at least 1,000 full open/close cycles and record total number of full cycles
5	Insure the excessive cycling does not overheat the actuator motor and cause premature failure
6	Record temperature rise of motor using a thermocouple.
7	Test passes if damper still operates properly at the conclusion of testing including opens, closes, and seals properly.

Actual Test:

The actual test was identical to the test plan with a single exception: the planned 1,000 full open/close cycles was reduced to an actual number of 550 full open/close cycles to save time at the lab. The primary purpose of this testing was to test and prove the process and modify it as needed, while preserving the damper and not testing it to failure.

The additional details involved in setting up and running the test are described here. The lab technician wired in a repeat cycle timer to the damper actuator to cycle the damper open and closed. A repeat cycle timer provides continuous on and off cycling of a load, in this case the damper actuator. The technician configured the timer to match the RTU's normal cycle for the damper open and close speeds. Initially, the test was ineffective as the excitation voltage to the timer was a bit too low and the timer would turn off at times and then not turn on. He used a DC power supply to set 24 volts to the timer. He added a thermocouple to the motor to verify that the motor isn't over heating when complete. The test proceeded as planned and the test passed.

Upon completion of the test, we began the next test (damper leakage), however shortly into the test it was determined the economizer was not modulating. After extensive diagnosis, we concluded the economizer control board was fried from too much voltage to the control board during the damper cycle test. We replaced the economizer control board with a new control board and the unit ran normally thereafter. No additional damper cycle testing was conducted.

Figure 89 Cycle timer used to modulate the economizer damper

Conclusions:

Testing the economizer under continuous actuations would require over a year assuming 3 minutes per full open/close cycle. This is best done by the economizer manufacturer, which they already do during product development and ongoing testing. Testing in the production environment may be possible, but would perhaps allow for only one full cycle actuation given production rates around 3 minutes or less per RTU. Testing at a third party would be prohibitively expensive.

The economizer damper cycle test is an intrusive test and risks damaging the RTU mechanical and electrical components. At the minimum, the economizer control board should have been disconnected from the actuator before applying voltage to the actuator.

Recommendation:

Require 5-year warranty of economizer assembly.

Require direct drive modulating actuator with gear driven interconnections.

Require product specification sheet proving capability at least 100,000 actuations.

100,000 actuations roughly corresponds to 18.4 years of service:

> 3 actuations/hr x 12 hrs/day x 7 days/wk x 52 wks/yr x 50% economizer season x 18.4 years EUL of RTU = 121,000 actuations … round down to 100,000

Damper Leakage

Purpose of Test:

The purpose of this test is to measure the economizer damper leakage as Title 24 2013 proposes a damper leakage standard. ASHRAE 90.1-2010 already requires ventilation outdoor air dampers be capable of automatically shutting off airflow during pre-occupancy warm-up, cool-down or setback modes.

Test Plans:

The initial test plan is as follows:

Table 6: Initial Damper Leakage Test

1	Set OAT to at least 20˚F lower than RAT
2	Run test with mechanical cooling disabled
3	Command return damper 100% open, outdoor damper 0% open
4	Adjust supply fan airflow such that the pressure differential across the outdoor damper is 1.0 in. w.g.
5	Measure OAT and RAT at existing sensor locations
6	Measure mixed air temp with grid arrangement after air filter (same as evaporator inlet temp)
7	Calculate OA damper leakage (cfm/sf of damper area) from temperature measurements and flow mixture equation
8	Test passes if outside air dampers have maximum airflow leakage rate of 10 cfm per sf at 1.0 in w.g. when tested according to AMCA Std 500-D-07: Airflow leakage rate using ambient air
	NOTE: AMCA Std 500-D-07 allows for ducts attached to the supply air outlet, the return air inlet, both, or neither. Leakage rate is from 90.1-2007 and Addendum.

Actual Test:

The preferred process is to use a code tester, which is the industry name for an airflow measurement device using a smooth nozzle orifice.

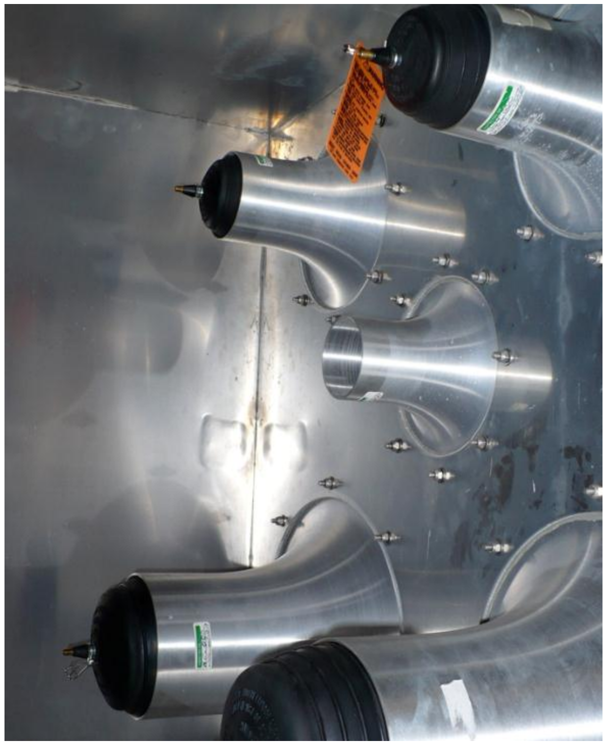


Figure 90 Code tester used to measure airflow

Conclusions:

The preferred process is to use a code tester, which is the industry name for an airflow measurement device using a smooth nozzle orifice. This process is impractical in the production environment. Testing at a third party would be rather expensive especially considering this is one of the least important elements of the economizer reliability certification.

In addition, research indicates that economizer damper leakage is already tested to AMCA Standard during product development and ongoing testing. Using the ASHRAE damper leakage analysis with CA costs of $0.16/kWh, the simple payback period ranges from 726 to 280,000 years depending on the climate zone. Therefore, it is questionable to justify 10 cfm/sf, just as ASHRAE concluded from their analysis and questionable to justify damper leakage testing and certification.

Recommendation:

Forgo damper leakage testing as part of the economizer certification, and instead require product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf.

Proper Integration between Economizer and Compressor

Purpose of Test:

The intent is to verify economizing can occur and provide partial cooling simultaneous with compressor cooling.

Test Plans:

The original test plan is outlined in the following table.

Table 7: Test of Integrated Economizer and Compressor

Step	Description	Purpose
1	Simulate OAT to 45°F and RAT to 75°F	
2	Generate call for cooling and increase OAT such that economizer damper modulates to position between minimum and 50% open with no mechanical cooling.	Test partial economizing at low OAT.
3	Verify economizer position is correct (between minimum and 50%) and stable with no hunting and the compressor is not enabled. Record the OAT and economizer damper position.	
4	Increase the OAT such that economizer damper modulates to position between 50% to 100% open with no mechanical cooling.	Test partial economizing.
5	Verify economizer modulates open to a larger degree, is stable with no hunting, the return air damper modulates more closed, and the compressor is not enabled. Record the OAT and economizer damper position.	
6	Increase the OAT such that the compressor turns on and the economizer damper modulates more closed.	Test partial economizing and compressor integration.
7	Verify the compressor is enabled. Record the OAT at high limit and the economizer damper position.	
8	Verify the compressor turns off and the economizer damper modulates to 100% open.	Test full economizing.
9	Record the compressor run time (minutes)	
10	Repeat Steps 7-8 when the compressor turns on again. Also verify the economizer damper modulates more closed.	Test partial economizing and compressor integration.
11	Record the compressor off time between cycles (minutes)	
12	Slowly increase the OAT such that mechanical cooling is enabled and the economizer damper modulates to minimum position	Test minimum ventilation and compressor integration.
13	Verify economizer position is correct and stable with no hunting and the compressor is enabled.	
14	Generate a call for heating	
15	Verify economizer damper modulates to minimum position and return air dampers open, with no hunting.	Test minimum ventilation and heating.
16	Record time it takes to achieve steady state operation	
17	Command the unit off	
18	Verify the economizer damper fully closes	

Actual Test:

The actual test proceeded as per the original test plan.

Conclusions:

Testing every unit on the production line after final assembly is impractical as the compressor needs a sizable cooling load to properly operate during the test. In addition, the times to achieve steady state operation are too long to be practical in a production environment.

Recommendation:

The recommendations are provided at the end of this Appendix.

Economizer High Limit Control and Deadband

Purpose of Test:

The intent is to verify the economizer high limit control, setpoint, and deadband.

It is preferable that an economizer controller will utilize a deadband between economizer enable/disable operation of no greater than 2°F in a dry-bulb temperature application and 2 Btu/lb in an enthalpy application.

Some existing controllers have a 10°F deadband, which severely limits economizer operation. A large deadband prevents the economizer from re-opening, even as the OA temperature drops below the high temperature lockout value, until the 10°F deadband is achieved. For example if the economizer high temperature lockout is set at 65°F, the economizer will be disabled when outdoor air temperature exceeds 65°F. However, the air temperature must drop to 55°F before the economizer will be re-enabled again. Thus, even if the outdoor temperature drops to 60°F, the economizer is locked out and mechanical cooling is used to satisfy a cooling load. This is not a very effective economizer control strategy.

Some controllers utilize a 0.5°F deadband. Two degrees is a reasonable deadband to maximize economizer operation and minimize the possibility of short-cycling the compressor.

A minimum economizer runtime or time delay may also be superimposed to keep the operation from becoming unstable and provide further compressor protection.

Test Plans:

The original test plan is outlined in the following table.

Table 8 Test of Economizer High Limit Control and Deadband

1	Disable compressor to prevent unwanted interaction
2	Set RAT to 80°F; OAT to 85°F
3	Generate a call for cooling
4	Verify that economizer is at minimum position
5	Incrementally lower the OAT by 1°F
6	Verify that economizer stays at minimum position until OAT is less than RAT (differential dry bulb control) or high limit setpoint (fixed dry bulb control), then opens to 100%
7	Reverse the process
8	Incrementally raise the OAT by 1°F
9	Verify that economizer stays at maximum position until OAT is higher than RAT (differential dry bulb control) or high limit setpoint (fixed dry bulb control), then closes to minimum position

10	Test passes if: i.) economizer controller will utilize a deadband between economizer enable/disable operation of no greater than 2°F and ii.) high limit control meets the requirements of Table 144-C as referenced in Title 24 Section 144(e)3.

Actual Test:

The initial test plan called for disabling the compressor to prevent unwanted interaction. This proved undesirable as the compressor must be enabled for the economizer to operate properly.

Conclusions:

Testing every unit on the production line after final assembly is impractical as the times to perform this test including achieving steady state operation are too long to be practical in a production environment.

Recommendation:

The recommendations are provided at the end of this Appendix.

Overall Conclusions

A number of barriers exist with regard to production line tests and third party test labs conducting economizer reliability testing. Specific tests can either be conducted on each make/model (instead of every single unit) or avoided through product specifications.

Specific barriers to utilizing a test lab include:

1) Need for testing technicians to be familiar with an unmanageable number of models.

RTUs would arrive to the test lab with default settings such as high-limit setpoint, global or local control, discharge air control cooling setpoint, fixed temperature high-limit, differential enthalpy high-limit, etc. Technicians would need to be familiar with every RTU make/model, its controller, and its economizer controller, in order to properly set up and conduct the testing. This is an unrealistic expectation. The current AHRI testing conducted by Intertek is much less intrusive to the RTU and requires much less familiarity with individual RTUs and their various controls.

Intertek's test facility in Cortland, NY conducts all the AHRI testing. This facility is overbooked and behind schedule. Their test facility in Plano, TX conducts development and other custom tests. They also operate at capacity. Neither facility is currently capable of taking on such a tremendous volume of work produced by our proposed requirement.

The CEC appliance efficiency database contains over 9,000 listings for small single-package air-cooled commercial units. 7,900 of these listings are for units between 33k to 65k Btu/h. 2,100 of these listings are for units between 54k to 65k Btu/h.

The database has 7,800 listings for large single-package air-cooled commercial units larger than 65k Btu/h. Thus, if the new economizer threshold is set at 33k Btu/h and larger, for example, then 15,700 models would be affected by a proposed economizer reliability certification. If the new economizer threshold is set at 54k Btu/h and larger, for example, then 9,900 models would be affected by a proposed economizer reliability certification.

2) Maintaining quality work by third-party labs may not be possible. The quality of work by Intertek technicians is prone to error, even under heavy supervision. Ultimately, third-party testing to encourage reliable economizers will not provide the level of quality assurance we envisioned.

Psychrometric rooms are not needed to functionally test temperature sensors, economizer damper cycles, damper leakage, high-limit control and deadband.

Overall Recommendations

Simple, non-intrusive tests are needed, which do not rely on custom setup for every RTU make/model, its controller, and its economizer controller.

Temperature sensor calibration: require product specification sheet showing sensor accuracy, hysteresis, and drift.

Economizer damper cycles: require product specification sheet proving capability at least 100,000 actuations. Require 5-year warranty of economizer assembly.

Damper leakage: require product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf.

Outlaw the snap-disk used for fixed dry-bulb high-limit control.

Require direct drive modulating actuator with gear driven interconnections.

The elements of the economizer certification per each individual unit (every serial number) are:

- High limit shut-off setpoint shall be set to the default limit settings (per Table 144-C as referenced in Section 144(e)3)
- Outside air dampers move freely without binding
- Minimum outside air damper position can be adjusted and outside and return air dampers modulate as necessary to achieve the desired position
- Outside air dampers completely close when the unit is off

The elements of the economizer certification per each make/model are:

Inspection

- Economizer is factory installed (except for custom, field-built RTUs)
- 5-year performance warranty of economizer assembly
- Direct drive modulating actuator with gear driven interconnections
- If the high-limit control is fixed dry-bulb, it shall have an adjustable setpoint
- Primary damper control temperature sensor located after the cooling coil to maintain comfort
- Provide an economizer specification sheet proving capability of at least 100,000 actuations
- Provide a product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf
- System is designed to provide up to 100% outside air without over-pressurizing the building

- Sensors used for the high limit control are calibrated with the following accuracies. This includes the outdoor air temperature or enthalpy sensor. This also includes the return air temperature or enthalpy sensor in the case of differential control.
  - Temperatures accurate to ± 1°F
  - Enthalpy accurate to within ± 1 Btu/lb
  - Relative humidity accurate to within 5%
- Sensor performance curve is provided with economizer instruction material. In addition, the sensor output value measured during sensor calibration is plotted on the performance curve.
- Sensors used for the high limit control are located to prevent false readings, e.g. properly shielded from direct sunlight

Functional Testing

Factory installed and calibrated economizer certification shall document that the following conditions are met:

- During a call for heating:
  - Outside air dampers close to a minimum ventilation position and return air dampers open
- Demonstrate proper integration between economizer and compressor:

Step	Description	Purpose
1	Simulate OAT to 45˚F and RAT to 75°F	
2	Generate call for cooling and increase OAT such that economizer damper modulates to position between minimum and 50% open with no mechanical cooling.	Test partial economizing at low OAT.
3	Verify economizer position is correct (between minimum and 50%) and stable with no hunting, compressor is not enabled, and heating is disabled. Record the OAT and economizer damper position.	
4	Increase the OAT such that economizer damper modulates to position between 50% to 100% open with no mechanical cooling.	Test partial economizing.
5	Verify economizer modulates open to a larger degree, is stable with no hunting, the return air damper modulates more closed, and the compressor is not enabled. Record the OAT and economizer damper position.	
6	Increase the OAT such that the compressor turns on and the economizer damper modulates more closed.	Test partial economizing and compressor integration.
7	Verify the compressor is enabled. Record the OAT at high limit and the economizer damper position.	
8	Verify the compressor turns off and the economizer damper modulates to 100% open.	Test full economizing.
9	Record the compressor run time (minutes)	
10	Repeat Steps 7-8 when the compressor turns on again. Also verify the economizer damper modulates more closed.	Test partial economizing and

		compressor integration.
11	Record the compressor off time between cycles (minutes)	
12	Slowly increase the OAT such that mechanical cooling is enabled and the economizer damper modulates to minimum position	Test minimum ventilation and compressor integration.
13	Verify economizer and return air damper positions are correct and stable with no hunting, compressor is enabled, and heating is disabled.	

Demonstrate economizer high limit control and deadband:

Step	Description	Purpose
1	Simulate RAT to 80˚F; OAT to 72˚F	
2	Generate a call for cooling	
3	Verify that economizer is at minimum position	Test minimum ventilation above the high limit setpoint.
4	Incrementally lower the OAT	
5	Verify that economizer stays at minimum position until ambient air conditions are less than high limit setpoint then opens to 100%	Test the high limit setpoint from above.
6	Reverse the process	Test the deadband.
7	Incrementally raise the OAT	
8	Verify that economizer stays at maximum position until ambient air conditions are higher than high limit setpoint then closes to minimum position	Test the high limit setpoint from below.
9	Test passes if: i.) economizer controller will utilize a deadband between economizer enable/disable operation of no greater than 2°F and ii.) high limit control meets the requirements of Table 144-C as referenced in Title 24 Section 144(e)3	

Appendix G: Manufacturer Certification to the California Energy Commission for Factory Installed and Calibrated Economizers

Air economizer acceptance testing is required by the 2008 California Building Energy Efficiency Standards (Title 24 Part 6) Section 125(a)4: “Air economizers shall be tested in accordance with NA7.5.4 Air Economizer Controls.” The purpose of this test is to assure that economizers work as per the intent of the Title 24 standards section 144(e) Economizers. The requirements of this acceptance test are described in the Reference Appendices to the Title 24 Building Efficiency Standards Section NA7.5.4 Air Economizer Controls. A detailed description of the test is located in Chapter 10 of the Nonresidential Compliance Manual: NA7.5.4 Air Economizer Controls Acceptance: “At-A-Glance” and “Test Procedure.”

Air economizers installed by the HVAC system manufacturer and certified to the CEC as being factory installed, calibrated and tested are exempted from the Functional Testing section of the Air Economizer Controls acceptance test as described in the Nonresidential Standards Reference Appendix NA7.5.4. The following sections describe the requirements of a “factory installed and calibrated economizer” certification and how to apply for CEC approval of a certification program. A brief discussion of the certification procedure is also included in the Compliance Manual: Section 10.5.6 “Factory Air Economizer Certification Procedure.”

Certification Requirements Per Each Individual Unit

The elements of the economizer certification per each individual unit (every serial number) are:

Inspection

- High limit shut-off setpoint shall be set to these default limit settings (per Table 144-C as referenced in Section 144(e)3):

Device Type	Climate Zones	Required High Limit (Economizer Off When): Equation [a]	Description
Fixed Dry Bulb	1, 3, 5, 11-16	$T_{OA} > 75°F$	Outdoor air temperature exceeds 75°F
	2, 4, 10	$T_{OA} > 73°F$	Outdoor air temperature exceeds 73°F
	6, 8, 9	$T_{OA} > 71°F$	Outdoor air temperature exceeds 71°F
	7	$T_{OA} > 69°F$	Outdoor air temperature exceeds 69°F
Differential Dry Bulb	1-5, 10-16	$T_{OA} > T_{RA}$	Outdoor air temperature exceeds return air temperature
Fixed Enthalpy	None [b]	N/A	N/A
Fixed Enthalpy + Fixed Drybulb	All	$h_{OA} > 28$ Btu/lb [c] or $T_{OA} > 75°F$	Outdoor air enthalpy exceeds 28 Btu/lb of dry air [c] or Outdoor air temperature exceeds 75°F
Electronic Enthalpy	All	$(T_{OA}, RH_{OA}) > A$	Outdoor air temperature/RH exceeds the "A" set-point curve [d]
Differential Enthalpy	None [b]	N/A	N/A

[a] Devices with selectable (rather than adjustable) setpoints shall be capable of being set to within 2°F and 2 Btu/lb of the listed setpoint.

[b] Fixed Enthalpy and Differential Enthalpy Controls are prohibited in all climate zones.

[c] At altitudes substantially different than sea level, the Fixed Enthalpy limit value shall be set to the enthalpy value at 75°F and 50% relative humidity. As an example, at approximately 6000 foot elevation the fixed enthalpy limit is approximately 30.7 Btu/lb.

[d] Set point "A" corresponds to a curve on the psychometric chart that goes through a point at approximately 75°F and 40% relative humidity and is nearly parallel to dry bulb lines at low humidity levels and nearly parallel to enthalpy lines at high humidity levels.

Functional Testing

- Outside air dampers move freely without binding
- Minimum outside air damper position can be adjusted and outside and return air dampers modulate as necessary to achieve the desired position
- Outside air dampers completely close when the unit is off

Certification Requirements Per Each Make/Model

The elements of the economizer certification per each make/model are:

Inspection

- Economizer is factory installed (except for custom, field-built RTUs)
- 5-year performance warranty of economizer assembly
- Direct drive modulating actuator with gear driven interconnections
- If the high-limit control is fixed dry-bulb, it shall have an adjustable setpoint
- Primary damper control temperature sensor located after the cooling coil to maintain comfort
- Provide an economizer specification sheet proving capability of at least 100,000 actuations

- Provide a product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf at 1.0 in w.g.
- System is designed to provide up to 100% outside air without over-pressurizing the building
- Sensors used for the high limit control are calibrated with the following accuracies. This includes the outdoor air temperature or enthalpy sensor. This also includes the return air temperature or enthalpy sensor in the case of differential control.
    - Temperatures accurate to ± 1°F
    - Enthalpy accurate to within ± 1 Btu/lb
    - Relative humidity accurate to within 5%
- Sensor performance curve is provided with economizer instruction material. In addition, the sensor output value measured during sensor calibration is plotted on the performance curve.
- Sensors used for the high limit control are located to prevent false readings, e.g. properly shielded from direct sunlight

Functional Testing

Factory installed and calibrated economizer certification shall document that the following conditions are met:

- During a call for heating:
    - Outside air dampers close to a minimum ventilation position and return air dampers open
- Demonstrate proper integration between economizer and compressor:

Step	Description	Purpose
1	Simulate OAT to 45˚F and RAT to 75°F	
2	Generate call for cooling and increase OAT such that economizer damper modulates to position between minimum and 50% open with no mechanical cooling.	Test partial economizing at low OAT.
3	Verify economizer position is correct (between minimum and 50%) and stable with no hunting, compressor is not enabled, and heating is disabled. Record the OAT and economizer damper position.	
4	Increase the OAT such that economizer damper modulates to position between 50% to 100% open with no mechanical cooling.	Test partial economizing.
5	Verify economizer modulates open to a larger degree, is stable with no hunting, the return air damper modulates more closed, and the compressor is not enabled. Record the OAT and economizer damper position.	
6	Increase the OAT such that the compressor turns on and the economizer damper modulates more closed.	Test partial economizing and compressor integration.
7	Verify the compressor is enabled. Record the OAT at high limit and the economizer damper position.	
8	Verify the compressor turns off and the economizer damper modulates to 100% open.	Test full economizing.

9	Record the compressor run time (minutes)	
10	Repeat Steps 7-8 when the compressor turns on again. Also verify the economizer damper modulates more closed.	Test partial economizing and compressor integration.
11	Record the compressor off time between cycles (minutes)	
12	Slowly increase the OAT such that mechanical cooling is enabled and the economizer damper modulates to minimum position	Test minimum ventilation and compressor integration.
13	Verify economizer and return air damper positions are correct and stable with no hunting, compressor is enabled, and heating is disabled.	

Demonstrate economizer high limit control and deadband:

Step	Description	Purpose
1	Simulate RAT to 80˚F; OAT to 72˚F	
2	Generate a call for cooling	
3	Verify that economizer is at minimum position	Test minimum ventilation above the high limit setpoint.
4	Incrementally lower the OAT	
5	Verify that economizer stays at minimum position until ambient air conditions are less than high limit setpoint then opens to 100%	Test the high limit setpoint from above.
6	Reverse the process	Test the deadband.
7	Incrementally raise the OAT	
8	Verify that economizer stays at maximum position until ambient air conditions are higher than high limit setpoint then closes to minimum position	Test the high limit setpoint from below.
9	Test passes if: i.) economizer controller will utilize a deadband between economizer enable/disable operation of no greater than 2°F and ii.) high limit control meets the requirements of Table 144-C as referenced in Title 24 Section 144(e)3	

Documents to Accompany Factory Installed and Calibrated Economizer Certificate

- Installation instructions shall include methods to assure economizer control is integrated and is providing cooling even when economizer cannot serve the entire cooling load.
- Sensor performance curve for high limit shut-off sensors and instructions for measuring sensor output. Performance curve shall also contain test points during calibration plotted on the curve. Curve details shall be accurate enough to show increments of 1°F and 1 Btu/lb.
- Economizer specification sheet proving capability of at least 100,000 actuations.
- Product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf at 1.0 in w.g.

Application for Factory Installed and Calibrated Economizer Certification

Manufacturers who wish to label their economizers as factory installed and calibrated must provide the following information to the California Energy Commission:

- Brief description of test method. This description must include:
  - Method of placing equipment in heating and cooling mode
  - Method of calibrating high limit sensor
  - Method of testing control and damper
- Model numbers of products to be certified
- Sample of Factory Installed and Calibrated Economizer documentation that would accompany each qualifying economizer.
- Name and contact information of lead staff in charge of certification

This request to certify economizers as factory installed and calibrated is sent to:

Mr. Tav Commins – MS 28
Building Efficiency Division
California Energy Commission
1516 Ninth St.
Sacramento, CA 95814

Appendix H: Sample Certificate Factory Installed and Calibrated Economizers

This document certifies that this economizer has been factory installed and calibrated according to the requirements of the California Energy Commission. This economizer is thus exempt from the functional testing requirement (but not the construction inspection requirement) as described in Standards Appendix NA7.5.4 “Air Economizer Controls” and on the MECH-5A acceptance form.

Date of economizer testing ________________

Supervisor ______________________________

Technician ______________________________

Model Number ___________________________

Serial Number ___________________________

Rated Cooling Capacity ___________________

Economizer fully integrated? Yes □ No □

Type of high limit control and setpoint **Check appropriate control strategy:**	**Device Type**	**Climate Zones**	**Required High Limit (Economizer Off When):**	
			Equation [a]	**Description**
†	Fixed Dry Bulb	1, 3, 5, 11-16	$T_{OA} > 75°F$	Outdoor air temperature exceeds 75°F
†		2, 4, 10	$T_{OA} > 73°F$	Outdoor air temperature exceeds 73°F
†		6, 8, 9	$T_{OA} > 71°F$	Outdoor air temperature exceeds 71°F
†		7	$T_{OA} > 69°F$	Outdoor air temperature exceeds 69°F
†	Differential Dry Bulb	1-5, 10-16	$T_{OA} > T_{RA}$	Outdoor air temperature exceeds return air temperature
†	Fixed Enthalpy	None [b]	N/A	N/A
†	Fixed Enthalpy + Fixed Drybulb	All	$h_{OA} > 28$ Btu/lb [c] or $T_{OA} > 75°F$	Outdoor air enthalpy exceeds 28 Btu/lb of dry air [c] or Outdoor air temperature exceeds 75°F
†	Electronic Enthalpy	All	$(T_{OA}, RH_{OA}) > A$	Outdoor air temperature/RH exceeds the "A" set-point curve [d]
†	Differential Enthalpy	None [b]	N/A	N/A

[a] Devices with selectable (rather than adjustable) setpoints shall be capable of being set to within 2°F and 2 Btu/lb of the listed setpoint.

[b] Fixed Enthalpy and Differential Enthalpy Controls are prohibited in all climate zones.

[c] At altitudes substantially different than sea level, the Fixed Enthalpy limit value shall be set to the enthalpy value at 75°F and 50% relative humidity. As an example, at approximately 6000 foot elevation the fixed enthalpy limit is approximately 30.7 Btu/lb.

[d] Set point "A" corresponds to a curve on the psychometric chart that goes through a point at approximately 75°F and 40% relative humidity and is nearly parallel to dry bulb lines at low humidity levels and nearly parallel to enthalpy lines at high humidity levels.

Outside Air Calibration

Outside air conditions during calibration test from reference measurement:

T_{OA} = _______ h_{OA} = _______

Outside air sensor output during calibration test:

T_{OA} = _______ h_{OA} = _______ Units (V, mA, etc.) = ___________

Sensor measured value from sensor performance curve: T_{OA} = _______ h_{OA} = _______

Are sensor measurements within 1°F and 1 Btu/lb of reference measurement? (Yes, No, N/A)

T_{OA} = _______ h_{OA} = _______

□ Sensor output plotted on sensor performance curve

□ Sensors used for the high limit control are properly shielded from direct sunlight

Return Air Calibration (for differential controls only)

Return air sensor during calibration test (if applicable): T_{return} = _______ h_{return} = _______

Return air sensor output during calibration test:

T_{return} = _____ h_{return} = _______ Units (V, mA, etc.) = __________

Sensor measured value from sensor performance curve T_{return} = _______ h_{return} = _______

Are sensor measurements within 1°F and 1 Btu/lb of reference measurement? (Yes, No, N/A)

T_{OA} = _______ h_{OA} = _______

□ Sensor output plotted on sensor performance curve

Functional Tests under Simulated Temperature Conditions

- During a call for heating, outside air dampers close to the minimum ventilation position and return air dampers open.
- During a call for full cooling with ambient conditions below the high limit shut-off setpoint, before mechanical cooling is enabled, outside air dampers open 100% and return dampers fully closed.
- During a call for full cooling with ambient conditions below the high limit shut-off setpoint and economizer cannot provide full cooling, then mechanical cooling and economizer are integrated to maximize economizer cooling. That is, the economizer provides partial cooling even when additional mechanical cooling is required to meet the remainder of the cooling load.
- During a call for cooling with ambient conditions above the high limit shut-off setpoint, outside air dampers close to the minimum ventilation position and return air dampers open.
- Minimum outside air can be adjusted.
- Outside air dampers close when the unit is off.
- Outside air dampers move freely without binding.

Accompanying Documents

- Installation instructions.
- Instructions shall include methods to assure economizer control is integrated and is providing cooling even when economizer cannot serve the entire cooling load.
- Economizer specification sheet proving capability of at least 100,000 actuations.
- Product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf at 1.0 in w.g.
- Performance curve for high limit shut-off sensors and instructions for measuring sensor output.

___________________ (company) certifies that all of the information on this Certificate for Factory Installed and Calibrated Economizers is true and that this economizer complies with all of the California Energy Commission requirements for Factory Installed and Calibrated Economizers.

Appendix I: Economizer Inspection and Functional Testing

The following table summarizes the inspection activities and functional testing associated with:

- Certification for a factory installed and calibrated economizer
- Current 2008 MECH-5A (Air Economizer Controls acceptance test)
- 2013 MECH-5A for field-installed economizers
- 2013 MECH-5A for factory installed and certified economizers

	Economizer installation:	Factory-installed	Factory or Field	Field-installed	Factory-installed
	Documentation:	Factory Certification	2008 MECH-5A	2013 MECH-5A	2013 MECH-5A
Construction inspection					
	Economizer lockout setpoint complies with Table 144-C per Standards Section 144(e)3.	x	x	x	x
	If the high-limit control is fixed dry-bulb, it shall have an adjustable setpoint	x		x	
	Economizer lockout control sensor is located to prevent false readings, e.g. shielded from direct sunlight	x	x	x	
	Primary damper control temperature sensor located after the cooling coil to maintain comfort	x		x	
	System is designed to provide up to 100% outside air without over-pressurizing the building.	x	x	x	
	For systems with DDC controls lockout sensor(s) are either factory calibrated or field calibrated.	x	x	x	
	For systems with non-DDC controls, manufacturer's startup and testing procedures have been applied		x	x	x
	Economizer damper moves freely without binding	x		x	x
	Provide an economizer specification sheet proving capability of at least 100,000 actuations	x			
	Provide a product specification sheet proving compliance with AMCA Standard 500 damper leakage at 10 cfm/sf	x		x	
	Unit has a direct drive modulating actuator with gear driven interconnections	x		x	
	Sensors used for the high limit control are calibrated at factory or in field	x		x	
	Sensor performance curve is provided by factory with economizer instruction material	x			
	Sensor output value measured during sensor calibration is plotted on the performance curve	x		x	
Functional testing					**Exempt**
	Enable the economizer:				
	Economizer damper opens	x	x	x	
	Return air damper closes	x	x	x	
	Economizer stays open when compressor comes on	x	x	x	
	Test partial economizing at low OAT	x			
	Test partial economizing at higher OAT	x			
	Test partial economizing and compressor integration	x			
	Test minimum ventilation and compressor integration	x			
	Demonstrate economizer high limit deadband	x			
	Building pressure is maintained		x	x	
	Heating is disabled	x	x	x	
	Disable the economizer:				
	Economizer damper closes to minimum	x	x	x	
	Building pressure is maintained		x	x	
	Heating is disabled	x	x	x	
	Simulate heating demand				
	Economizer damper closes to minimum	x	x	x	
	Return air damper opens	x		x	
	Turn the unit off				
	Verify the economizer damper closes	x		x	

Appendix J: Market Survey for Thermostats

The goal of this market survey was to determine the functional differences and costs of various models of single-stage and two-stage commercial thermostats with and without capability for occupancy sensor input.

Why: Proposed Title 24 Requirements (2-stage thermostat with occupany sensor input for zones requiring occupancy sensor; used to setback the temperature when the zone is unoccupied. The base-case is 1-stage setback thermostat without occupancy sensor input.)

Questions:

What products would you recommend for 2-stage commercial thermostats that accept an input from an occupancy sensor? (list make/model/features)

So these products allow for temperature setpoint set-up and set-back according to the occupancy sensor input to the t-stat?

What are comparable products but only 1-stage cooling and without an occupancy sensor input? (list make/model/features; must have programmable setback capability)

What are comparable products with 2-stages of cooling and without an occupancy sensor input? (list make/model/features; must have programmable setback capability)

Would you be willing to provide the costs for these products?

What would be the # hours for a certified electrician to complete the installation? (New construction and replacement)

> What about for a similar t-stat but without an occupancy sensor input? (NC and repl)
> Include the time for programming the schedule and setbacks if needed.
> Include time for running wire between t-stat and occ sensor.
> Do not include time for installing occupancy sensor. (already installed per baseline case)

Can you provide any thoughts on the relative quality of the t-stats you carry and any additional insights you have about t-stats with occ sensor input?

Specifically, how does a 2-stage thermostat with an occupancy sensor input differ from one without an occupancy sensor input? (with respect to function)
Maintenance?
Reliability?
Expected Lifetime?
Common Failure Modes?

Do most of the products that you rep come pre-programmed with a set schedule? Do installers typically leave it or re-program with a different schedule?

What is a typical number of degrees ˚F for set-up and set-back? Do you hear of comfort complaints when people reenter the room after it's been set-up/set-back?

Can you provide any thoughts on the relative quality of the thermostats that you rep and any additional insights about thermostats with occupancy sensor input?

Ask for: Cut sheets, documentation, product line information, etc.

Appendix K: Modeling Guidance for RTU Economizers

This section provides guidance for DOE 2.2/eQUEST modeling of economizers on packaged single zone (PSZ) systems. There is a known issue with DOE 2.2 in regard to modeling PSZ systems. The program models a fully integrated economizer strategy instead of an alternating economizer strategy better suited for PSZ systems. This is not a widely known issue, thus the issue and a work-around are described here.

PSZ DX Unit Economizer Simulation

There are several key elements to be included in the simulation of the economizer. These are included in the table below along with typical baseline and measure inputs. The main categories are discussed in more detail later.

BDL Keyword	Discussion	Typical Baseline	Typical Measure
OA_CONTROL	In the Western US, dry bulb changeover controls are appropriate. Enthalpy controls may be encountered, but save little and are usually out of calibration.[xlvi]	OA-TEMP	OA-TEMP
DRYBULB-LIMIT	The baseline economizer with a snap disc will use 55°F; an adjustable setting might be up to 60°F, but not higher with a single stage thermostat.	55°F to 60°F	70°F to 75°F
ECONO-LOCKOUT	With a single stage thermostat, economizer and mechanical cooling cannot operate simultaneously; with two stages they can.	YES	NO
MAX-OA-FRACTION	The best an economizer without relief air can provide is 50% OSA.	0.5	0.7
ECONO-LOW-LIMIT	Best left blank, as not implemented in most control sequences.	n/a	n/a

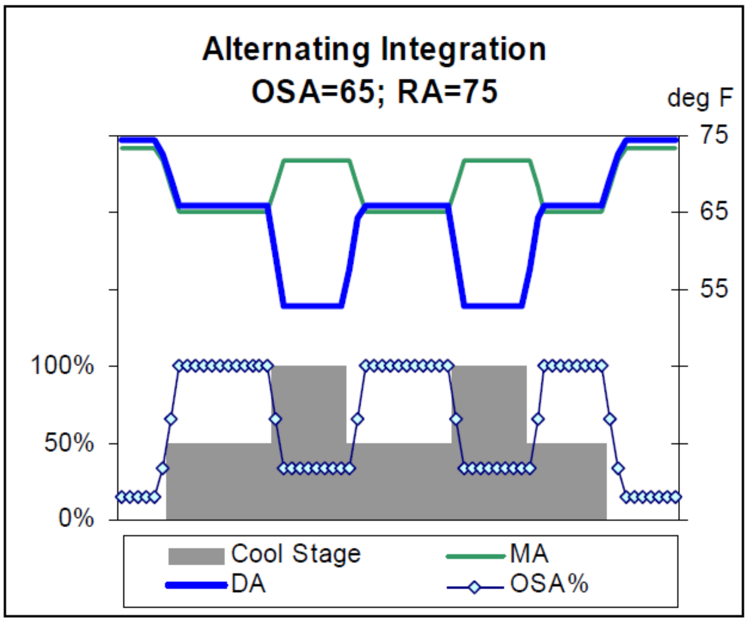
PSZ DX Unit Economizer Simulation Issue

Simulating Packaged Single Zone (PSZ) systems using single stage DX cooling coils with outside air economizers in DOE 2.2 will overstate energy savings. This is because the program models a fully integrated economizer strategy instead of an alternating economizer strategy better suited for PSZ systems. In actuality, a single-stage DX cooling unit must throttle back the outside air during integrated operation.

As an hourly simulation program, DOE 2.2 cannot simulate switching between a single stage DX coil cooling operation (that needs to reduce the outside air to avoid comfort problems and coil freezing) and economizer operation where supply air temperature is not an issue. The present routine exaggerates the savings that will accrue from an economizer in a single-stage cooling unit.

Non-integrated or exclusive operation: Below the changeover temperature, only the economizer operates. Above the changeover setting, only the cooling coil operates. They never operate at the same time. To maintain comfort, a non-integrated economizer changeover is usually set for OSA above 50˚F or 55˚F, although with experimentation, some spaces can achieve comfort with changeover settings around 60˚F.

Alternating integration: This is the best integration that can be achieved with a single-stage direct-expansion cooling unit. As shown in the graph, the first cooling stage from the thermostat activates the economizer. When the temperature rises further, the second thermostat stage is activated and the cooling compressor operates. With the coil on and the primary sensor in the discharge air position, the economizer controller modulates the outside air dampers closed (usually to or near the minimum ventilation position) to keep discharge air from getting too cold for comfort and to prevent coil icing. When the space temperature drops and the second stage is satisfied, the compressor stops and the economizer opens again to provide maximum outside air economizing until the first stage of cooling is satisfied or the second stage is activated again. Note that in the example figure below, the OSA damper does not close all the way to the minimum position; if the OSA was cooler or the return air warmer, it would.

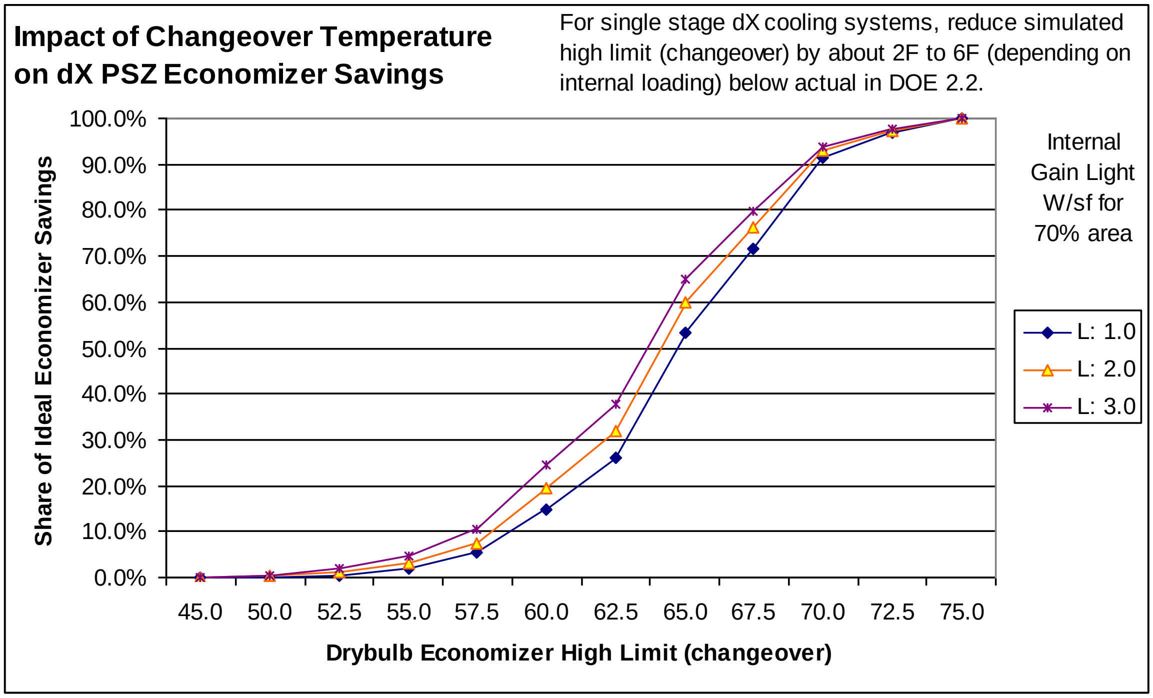


Full integration: A hydronic chilled-water cooling coil can be modulated to any cooling output. This allows the economizer to be fully open when outside air is above the discharge air setpoint (usually 55˚F) and add only the amount of mechanical cooling that is actually needed. For full integration to be achieved, a differential changeover strategy is required.

PSZ DX Unit Economizer DRYBULB-LIMIT Work-Around

In order to simulate an alternating economizer strategy in DOE 2.2 a work around has been developed and described here.[xlvii]

Note that the economizer savings is quite dependent on the high limit setting. Especially when the high limit falls below 70˚F, there is a significant drop off in provided economizer savings as shown in the graph. In the models used for the graph, lighting power density is used as a proxy for internal building loads.



Even though some have advocated a fully integrated approach with single-stage DX coils, in practice this strategy will result in low discharge air temperatures causing coil freezing and comfort complaints. In response to these problems, contractors and technicians frequently cut control wires therefore disabling the economizer entirely. To avoid these issues, an alternating approach is recommended where the economizer and mechanical cooling modes alternate based on discharge air temperatures. Further explanation of the alternating strategy is discussed in more detail in the background section of this document.

In order to model an alternating integrated economizer strategy in DOE 2.2, the economizer high limit (or changeover setting) is modified. This setting describes the highest outdoor air temperature for which the economizer is allowed to function. For all temperatures above this setting only mechanical cooling is allowed. Because the savings are typically exaggerated with a fully integrated approach, the high limit setting modeled in DOE2.2 is set lower than the high limit setting programmed into the RTU’s control system. Lowering the high limit setting reduces the economizer run hours and savings mimicking an alternating integration strategy.

The modeled high limit setting is a function of occupant density, lighting Watt/SQFT and the RTU’s actual high limit setting. The first table below gives the new high limit temperature for low density areas like offices while the second table gives the adjusted high limit temperatures for high density areas like assembly areas. The tables also list three different high limit values depending on the lighting Watt/SQFT listed as light, medium, and heavy.

In order to use these tables for a specific application, the user must first pick which occupant density (low or high) best describes the conditioned space then choose the appropriate table. The high limit temperature setting from the specific RTU economizer controller indicates which OAT (shown on the left hand column of the table) should be selected for the baseline. Following that to the right are three choices for the adjusted high limit temperature based on the lighting Watt/SQFT. Choosing which lighting load best describes the specific building type will allow the user to choose the correct adjusted high limit temperature. This value should be input into eQUEST model under the "Air-Side HVAC Parameters" window as the "Drybulb High Limit Parameter (DRYBULB-LIMIT)." The figure below shows the location of the parameter within the window. The parameter titled "Lockout Compressor" should also be specified as "No" for the improved economizer with a two-stage thermostat.

Table 1: High Limit Adjustment – Low Density Occupancies

Adjusting DOE 2.2 PSZ from full integration to alternating integration

Low Density Occupancies such as offices

OAT	Adjusted High Limit Input			Reduction in High Limit		
Balance:	57	52	47	**57**	**52**	**47**
OAT	Light	Med	Heavy	Light	Med	Heavy
75.0	73.8	71.7	69.9	*1.2*	**3.3**	**5.1**
72.5	71.7	70.1	69.9	*0.8*	**2.4**	**2.6**
70.0	69.8	69.3	68.7	0.2	*0.7*	*1.3*
67.5	67.3	66.8	66.2	0.2	*0.7*	*1.3*
65.0	64.9	64.7	64.4	0.1	0.3	*0.6*
62.5	62.4	61.9	61.4	0.1	*0.6*	*1.1*
60.0	59.9	59.6	59.3	0.1	0.4	*0.7*
57.5	57.5	57.0	56.4	0.0	0.5	*1.1*
55.0	55.0	54.7	54.2	0.0	0.3	*0.8*

Internal loads are characterized as light, medium and heavy.

Heavy: Lighting at 2.3 Watts/square foot with high occupancy; Call center

Medium: Lighting at 1.7 Watts/square foot; moderate occupancy; open office

Light: Lighting at 0.7 Watts/square foot with low density occupancy

Table 2: High Limit Adjustment – High Density Occupancies

Adjusting DOE 2.2 PSZ from full integration to alternating integration

High Density Occupancies (with increased ventilation)

OAT	Adjusted High Limit Input			Reduction in High Limit		
Balance:	52	47	37	**52**	**47**	**37**
Hi Limit	Light	Med	Heavy	Light	Med	Heavy
75.0	72.6	71.0	69.4	**2.4**	**4.0**	**5.6**
72.5	71.0	69.3	69.3	*1.5*	**3.2**	**3.2**
70.0	69.6	69.1	68.1	0.4	*0.9*	*1.9*
67.5	67.1	66.6	65.7	0.4	*0.9*	*1.8*
65.0	64.7	64.5	64.1	0.3	0.5	*0.9*
62.5	61.9	61.5	60.7	*0.6*	*1.0*	*1.8*
60.0	59.5	59.1	58.5	*0.5*	*0.9*	*1.5*
57.5	56.6	55.8	54.6	*0.9*	*1.7*	**2.9**
55.0	53.8	52.8	51.7	*1.2*	**2.2**	**3.3**

Internal loads are characterized as light, medium and heavy.

Heavy: Retail with high lighting or appliance and people density

Medium: Moderately full classrooms, meeting rooms, and lecture halls

Light: Theatre or assembly with intermittent occupancy, low light levels

Development of Work-Around Findings

The biggest impact on economizer savings is the high limit or changeover setting. An office and assembly area were simulated with a range of internal loading. High density occupancies like assembly areas have higher base ventilation rates, impacting the relative economizer savings. The impact of operating conditions on economizer performance was estimated by following the following steps:

- Cooling loads and occupied hours for a typical space were determined by outside bin temperature.
- The maximum amount of outside air allowed at various outside temperatures to avoid discharge temperatures below 53°F was determined.
- Based on loads vs design conditions, the time of economizer operation in each bin was determined.
- The net sensible cooling economizer impact for alternating integration at each bin temperature was found as a percentage of cooling provided with a fully integrated economizer.
- DOE 2.2 runs for 2.5°F increments of economizer high limit setpoint were run to find the percentage of full (75°F economizer high limit setpoint) economizer cooling provided.
- The previously found percentage of savings for an alternating integration was compared with the results of the PSZ model setpoint with interpolation to find the equivalent high limit setpoint.
- The results were re-run for both Portland, Oregon and Sacramento, California and it was found that climate differences were trivial since the analysis was based on percentage of full economizer operation. It was found that the impact of internal loading and occupancy density were important factors to consider.

Development of Adjustment Values

The adjustment values were developed using a simplified bin method to determine the percentage of full integrated ventilation delivered by alternating integration, and then using those percentage reductions in savings to select adjustments to the changeover based on matching the reduction in economizer savings found from multiple DOE2 parametric runs.

The first step was to find the percentage of full cooling load for each temperature bin (2.5°F bins were used). To find if there was sensitivity to climate, there were runs completed for both Portland, Oregon and Sacramento, California. The cooling loads for a light, medium, and heavy internally loaded building, along with Bin hour percentages for the economizer outside temperature ranges are shown in and . The bin cooling loads for light, medium, and heavy loads are based on balance points, where there is no cooling load due to heat losses balancing internal heat gains of 57°F, 52°F, and 47°F outside temperature respectively.

In the end, the resulting temperature adjustments for both Portland and Sacramento were compared, and all found to be within +/- 0.77°F. This is within the range of precision for changeover settings, so it is found expedient to use one adjustment table for all climate zones.

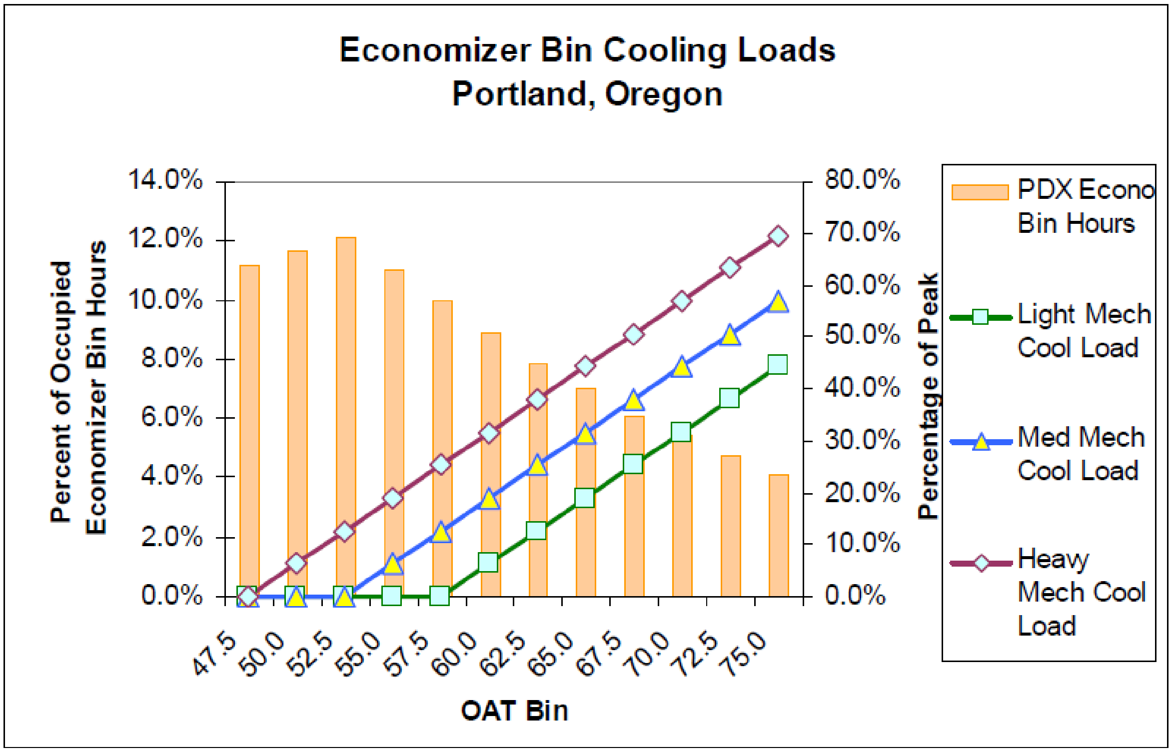


Figure 91 Portland Cooling Loads in Economizer Range

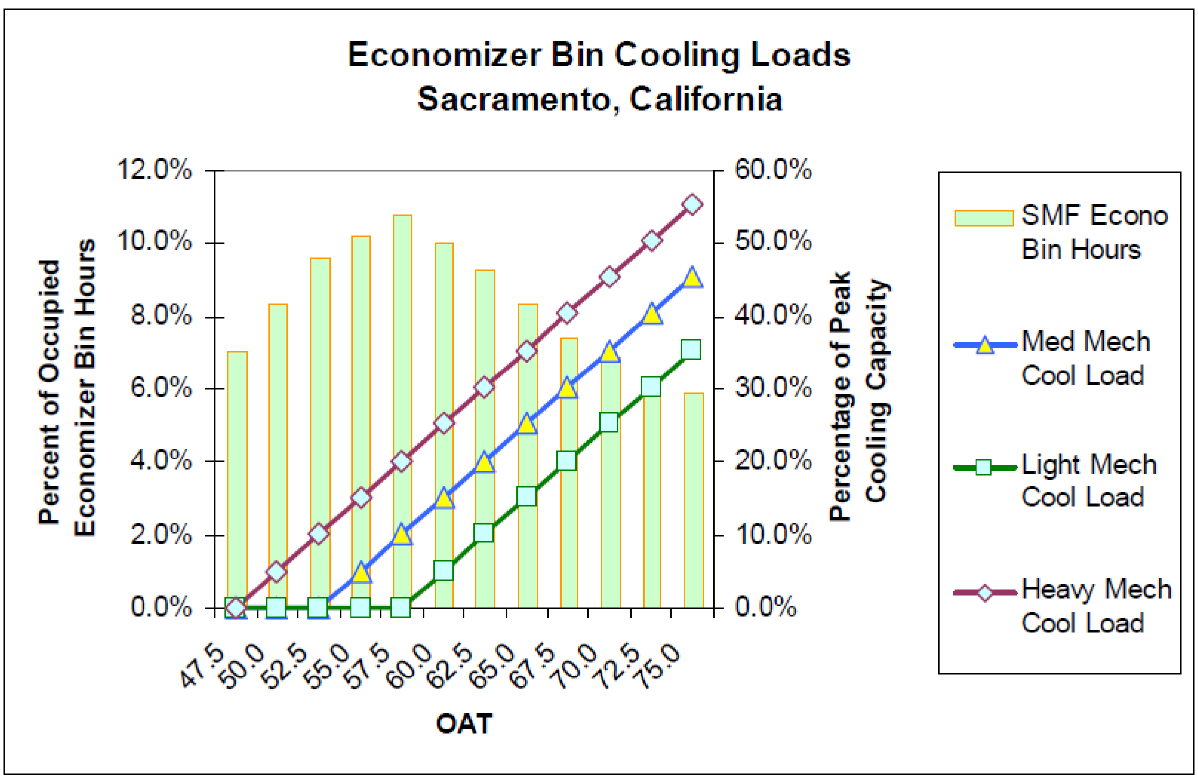
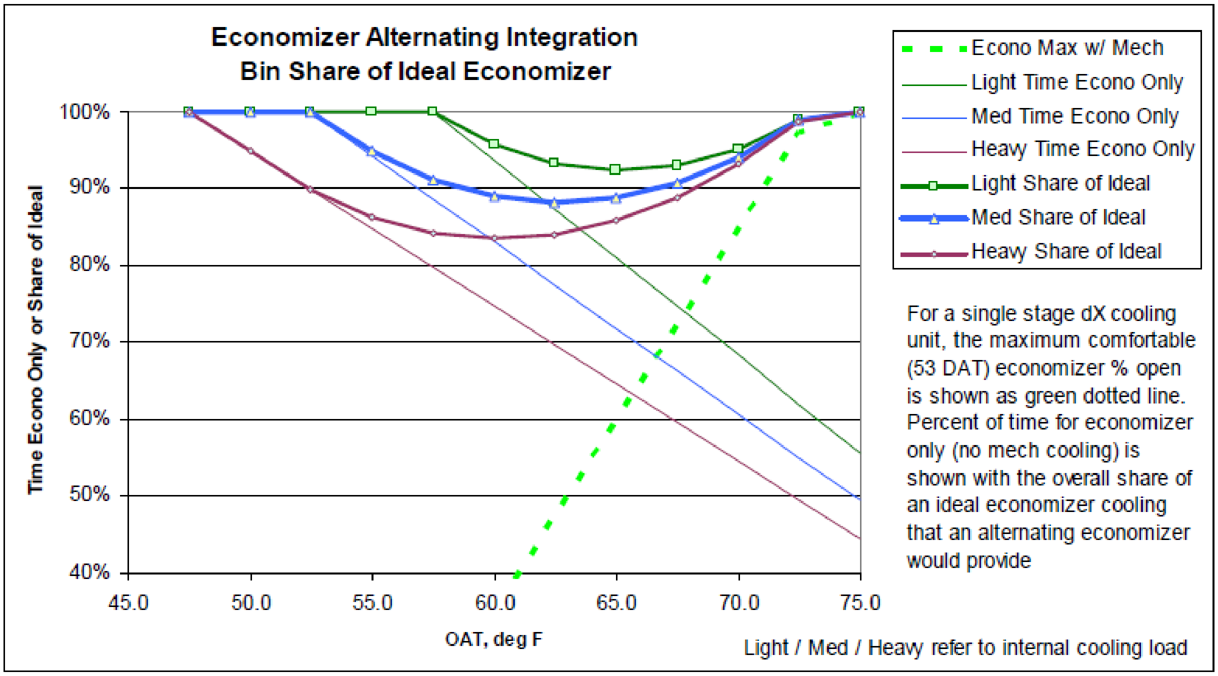
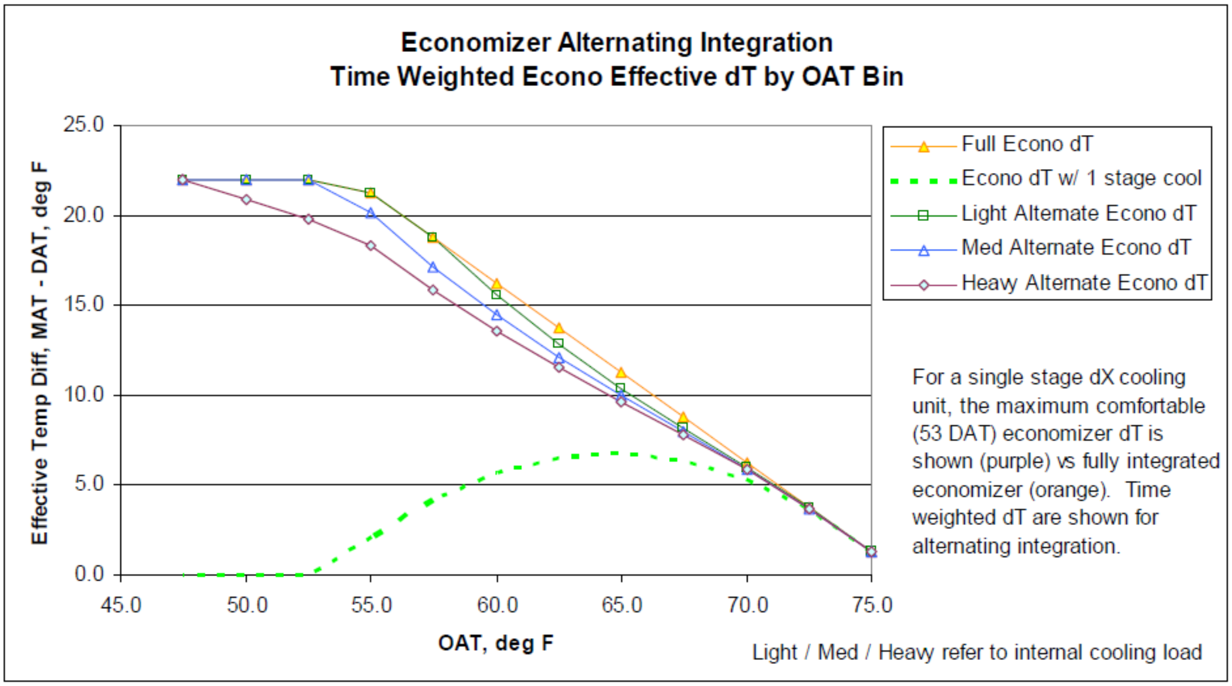


Figure 92 Sacramento Cooling Loads in Economizer Range

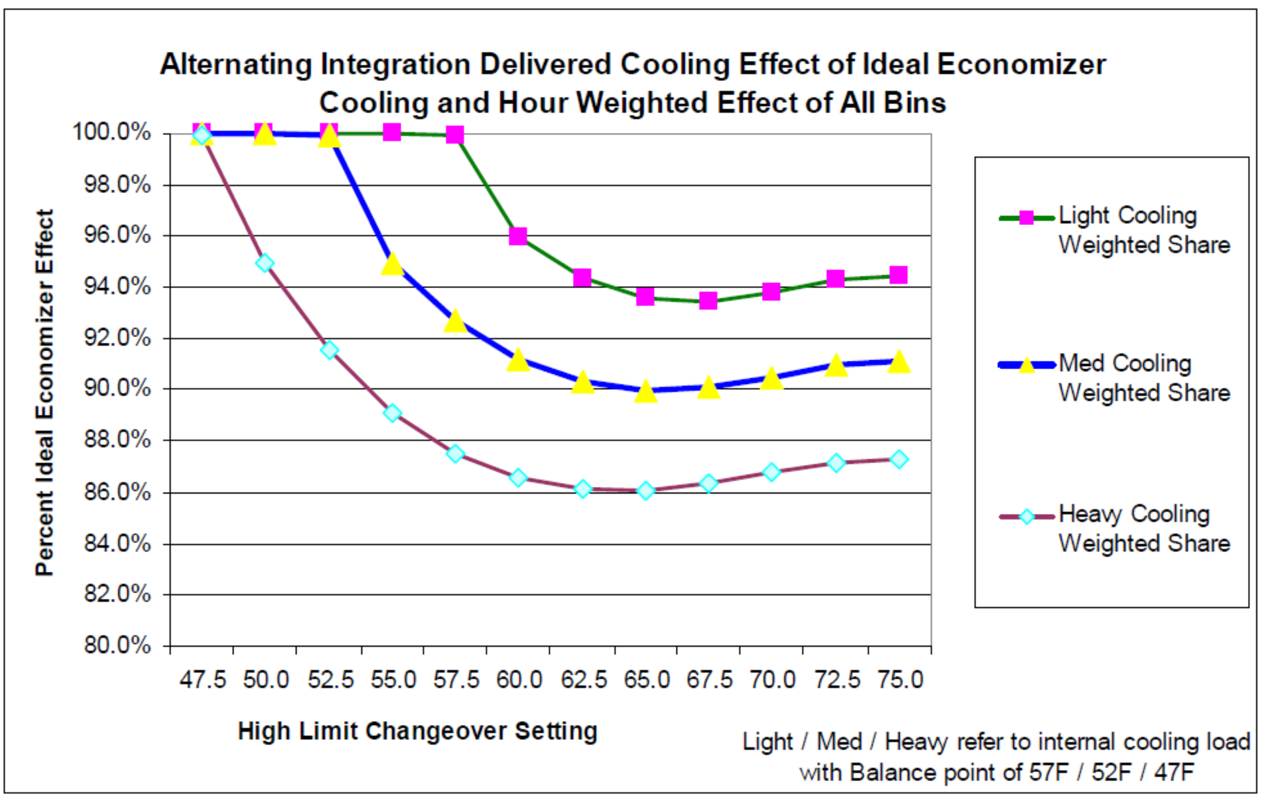
The next step is to find for each temperature Bin, the Share of ideal (fully integrated with fully modulating cooling) economizer provided by an alternating integration economizer. This share is a function of the amount of time the economizer operates without the cooling coil operating (during this time, full economizer capability is provided) and the percentage of economizer that can be provided with the cooling coil full on to avoid having a DAT lower than 53°F, assuming a 20°F sensible coil temperature drop. Note that this analysis is based on sensible temperature, and that is appropriate for the western United States, where humidity levels are not high. The percentage of economizer allowed with the cooling on, the share of time for Economizer only, and the resulting alternating integration for each Bin is shown below.



The sensible temperature difference for an ideal economizer and for an economizer working with the cooling coil are shown below, along with the time weighted effective temperature difference for an alternating integrated economizer.



The impact of the alternating integration deduct is integrated across all economizer bins, weighting by cooling load, occupied bin hours, and ideal economizer benefit, as seen below.



Appendix L: Energy Savings for High Limit Switch

	ANNUAL ELECTRICITY USE		CZ1	CZ2	CZ3	CZ4
	OA-CONTROL	Setpoint	kWh/yr	kWh/yr	kWh/yr	kWh/yr
Base	FIXED	n/a	383,190	413,337	405,568	420,722
Run 1	FIXED-DB	67	357,519	394,719	381,868	401,807
Run 2	FIXED-DB	69	357,509	394,482	381,600	401,494
Run 3	FIXED-DB	71	357,504	394,310	381,393	401,300
Run 4	FIXED-DB	73	357,503	394,239	381,381	401,174
Run 5	FIXED-DB	75	357,505	394,298	381,422	401,263
Run 6	FIXED-DB	77	357,507	394,538	381,465	401,610
Run 7	DUAL-TEMP	n/a	357,502	394,257	381,399	401,208
Run 8	DUAL-TEMP -4	n/a	357,507	394,816	381,522	401,917
Run 9	DUAL-TEMP +4	n/a	357,507	394,394	381,416	401,383
Run 10	OA-ENTHALPY	28	357,513	395,008	381,501	401,614
Run 11	OA-ENTHALPY	26	357,660	394,655	381,828	401,725
Run 12	OA-ENTHALPY	30	357,522	396,804	381,952	403,343
Run 13	DUAL-ENTHALPY	n/a	357,504	394,317	381,377	401,257
Run 14	DUAL-ENTHALPY + DB HIGH	75	357,502	394,200	381,358	401,153
Run 15	DUAL-ENTHALPY -4	n/a	357,522	397,813	382,010	404,862
Run 16	DUAL ENTHALPY +4	n/a	360,403	398,344	388,571	407,779
Run 17	DUAL-ENTHALPY -4 (+DB)	73	357,503	394,239	381,381	401,174
Run 18	DUAL ENTHALPY +4 (+DB)	77	360,403	398,344	388,571	407,779
Run 19	Dewpoint + DB	55+75	359,339	395,074	384,072	403,105
Run 20	Dewpoint(-5) + DB	50+73	370,735	400,636	393,419	409,573
Run 21	Dewpoint(+5) + DB	60+77	357,583	394,520	381,461	401,560
Run 22	Electronic Enthalpy A	~73/31	357,503	394,239	381,381	401,168
Run 23	Electronic Enthalpy A (+2)	~75/33	357,505	394,298	381,422	401,263
Run 24	Electronic Enthalpy A (-2)	~71/29	357,504	394,310	381,392	401,302

	SAVINGS COMPARED TO NO ECONOMIZER		CZ1		CZ2		CZ3		CZ4	
Run	OA-CONTROL	Setpoint	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max
1	FIXED-DB	67	25,671	**99.9%**	18,618	**97.3%**	23,700	**97.9%**	18,915	**96.7%**
2	FIXED-DB	69	25,681	**100.0%**	18,855	**98.5%**	23,968	**99.0%**	19,228	**98.3%**
3	FIXED-DB	71	25,686	**100.0%**	19,027	**99.4%**	24,175	**99.8%**	19,422	**99.2%**
4	FIXED-DB	73	25,687	**100.0%**	19,098	**99.8%**	24,187	**99.9%**	19,548	**99.9%**
5	FIXED-DB	75	25,685	**100.0%**	19,039	**99.5%**	24,146	**99.7%**	19,459	**99.4%**
6	FIXED-DB	77	25,683	**100.0%**	18,799	**98.2%**	24,103	**99.5%**	19,112	**97.7%**
7	DUAL-TEMP	n/a	25,688	**100.0%**	19,080	**99.7%**	24,169	**99.8%**	19,514	**99.7%**
8	DUAL-TEMP -4	n/a	25,683	**100.0%**	18,521	**96.8%**	24,046	**99.3%**	18,805	**96.1%**
9	DUAL-TEMP +4	n/a	25,683	**100.0%**	18,943	**99.0%**	24,152	**99.8%**	19,339	**98.8%**
10	OA-ENTHALPY	28	25,677	**100.0%**	18,329	**95.8%**	24,067	**99.4%**	19,108	**97.6%**
11	OA-ENTHALPY	26	25,530	**99.4%**	18,682	**97.6%**	23,740	**98.1%**	18,997	**97.1%**
12	OA-ENTHALPY	30	25,668	**99.9%**	16,533	**86.4%**	23,616	**97.5%**	17,379	**88.8%**
13	DUAL-ENTHALPY	n/a	25,686	**100.0%**	19,020	**99.4%**	24,191	**99.9%**	19,465	**99.5%**
14	DUAL-ENTHALPY + DB HIGH	varies	25,688	**100.0%**	19,137	**100.0%**	24,212	**100.0%**	19,569	**100.0%**
15	DUAL-ENTHALPY -4	n/a	25,668	**99.9%**	15,524	**81.1%**	23,558	**97.3%**	15,860	**81.0%**
16	DUAL ENTHALPY +4	n/a	22,787	**88.7%**	14,993	**78.3%**	16,997	**70.2%**	12,943	**66.1%**
17	DUAL-ENTHALPY -4 (+DB)	73	25,687	**100.0%**	19,098	**99.8%**	24,187	**99.9%**	19,548	**99.9%**
18	DUAL ENTHALPY +4 (+DB)	77	22,787	**88.7%**	14,993	**78.3%**	16,997	**70.2%**	12,943	**66.1%**
19	Dewpoint + DB	55+75	23,851	**92.8%**	18,263	**95.4%**	21,496	**88.8%**	17,617	**90.0%**
20	Dewpoint(-5) + DB	50+73	12,455	**48.5%**	12,701	**66.4%**	12,149	**50.2%**	11,149	**57.0%**
21	Dewpoint(+5) + DB	60+77	25,607	**99.7%**	18,817	**98.3%**	24,107	**99.6%**	19,162	**97.9%**
22	Electronic Enthalpy A	~73/31	25,687	**100.0%**	19,098	**99.8%**	24,187	**99.9%**	19,554	**99.9%**
23	Electronic Enthalpy A (+2)	~75/33	25,685	**100.0%**	19,039	**99.5%**	24,146	**99.7%**	19,459	**99.4%**
24	Electronic Enthalpy A (-2)	~71/29	25,686	**100.0%**	19,027	**99.4%**	24,176	**99.9%**	19,420	**99.2%**

Table 9 – Energy Savings for Prototype Building – Climate Zones 1 - 4

	ANNUAL ELECTRICITY USE		CZ5	CZ6	CZ7	CZ8
	OA-CONTROL	Setpoint	kWh/yr	kWh/yr	kWh/yr	kWh/yr
Base	FIXED	n/a	405,188	432,645	433,857	437,699
Run 1	FIXED-DB	67	383,710	415,297	412,484	421,794
Run 2	FIXED-DB	69	383,307	414,830	412,102	421,476
Run 3	FIXED-DB	71	383,097	414,817	412,350	421,170
Run 4	FIXED-DB	73	383,046	415,850	413,262	421,253
Run 5	FIXED-DB	75	383,087	417,132	413,933	421,765
Run 6	FIXED-DB	77	383,169	418,129	414,269	422,453
Run 7	DUAL-TEMP	n/a	383,072	416,668	413,792	421,725
Run 8	DUAL-TEMP -4	n/a	383,235	418,553	414,378	423,350
Run 9	DUAL-TEMP +4	n/a	383,186	414,760	412,124	421,213
Run 10	OA-ENTHALPY	28	383,264	415,508	412,643	422,182
Run 11	OA-ENTHALPY	26	383,681	418,125	414,559	423,655
Run 12	OA-ENTHALPY	30	383,454	415,710	412,212	422,400
Run 13	DUAL-ENTHALPY	n/a	383,115	414,974	412,468	421,624
Run 14	DUAL-ENTHALPY + DB HIGH	75	383,055	414,910	412,434	421,427
Run 15	DUAL-ENTHALPY -4	n/a	383,521	418,354	413,961	425,417
Run 16	DUAL ENTHALPY +4	n/a	389,306	424,571	424,055	429,829
Run 17	DUAL-ENTHALPY -4 (+DB)	73	383,046	415,827	413,160	421,253
Run 18	DUAL ENTHALPY +4 (+DB)	77	389,306	424,571	424,055	429,829
Run 19	Dewpoint + DB	55+75	384,795	420,813	417,613	425,590
Run 20	Dewpoint(-5) + DB	50+73	393,705	426,006	424,433	429,448
Run 21	Dewpoint(+5) + DB	60+77	383,154	416,681	412,948	422,490
Run 22	Electronic Enthalpy A	~73/31	383,046	415,584	412,403	421,216
Run 23	Electronic Enthalpy A (+2)	~75/33	383,087	417,102	413,594	421,765
Run 24	Electronic Enthalpy A (-2)	~71/29	383,097	414,835	412,158	421,212

	SAVINGS COMPARED TO NO ECONOMI		CZ5		CZ6		CZ7		CZ8	
Run	OA-CONTROL	Setpoint	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max
1	FIXED-DB	67	21,478	97.0%	17,348	97.0%	21,373	98.2%	15,905	96.2%
2	FIXED-DB	69	21,881	98.8%	17,815	99.6%	21,755	100.0%	16,223	98.1%
3	FIXED-DB	71	22,091	99.8%	17,828	99.7%	21,507	98.9%	16,529	100.0%
4	FIXED-DB	73	22,142	100.0%	16,795	93.9%	20,595	94.7%	16,446	99.5%
5	FIXED-DB	75	22,101	99.8%	15,513	86.7%	19,924	91.6%	15,934	96.4%
6	FIXED-DB	77	22,019	99.4%	14,516	81.2%	19,588	90.0%	15,246	92.2%
7	DUAL-TEMP	n/a	22,116	99.9%	15,977	89.3%	20,065	92.2%	15,974	96.6%
8	DUAL-TEMP -4	n/a	21,953	99.1%	14,092	78.8%	19,479	89.5%	14,349	86.8%
9	DUAL-TEMP +4	n/a	22,002	99.4%	17,885	100.0%	21,733	99.9%	16,486	99.7%
10	OA-ENTHALPY	28	21,924	99.0%	17,137	95.8%	21,214	97.5%	15,517	93.9%
11	OA-ENTHALPY	26	21,507	97.1%	14,520	81.2%	19,298	88.7%	14,044	85.0%
12	OA-ENTHALPY	30	21,734	98.2%	16,935	94.7%	21,645	99.5%	15,299	92.6%
13	DUAL-ENTHALPY	n/a	22,073	99.7%	17,671	98.8%	21,389	98.3%	16,075	97.3%
14	DUAL-ENTHALPY + DB HIGH	varies	22,134	100.0%	17,741	99.2%	21,424	98.5%	16,272	98.4%
15	DUAL-ENTHALPY -4	n/a	21,667	97.9%	14,291	79.9%	19,896	91.5%	12,282	74.3%
16	DUAL ENTHALPY +4	n/a	15,882	71.7%	8,074	45.1%	9,802	45.1%	7,870	47.6%
17	DUAL-ENTHALPY -4 (+DB)	73	22,142	100.0%	16,818	94.0%	20,697	95.1%	16,446	99.5%
18	DUAL ENTHALPY +4 (+DB)	77	15,882	71.7%	8,074	45.1%	9,802	45.1%	7,870	47.6%
19	Dewpoint + DB	55+75	20,393	92.1%	11,832	66.2%	16,244	74.7%	12,109	73.3%
20	Dewpoint(-5) + DB	50+73	11,483	51.9%	6,639	37.1%	9,424	43.3%	8,251	49.9%
21	Dewpoint(+5) + DB	60+77	22,034	99.5%	15,964	89.3%	20,909	96.1%	15,209	92.0%
22	Electronic Enthalpy A	~73/31	22,142	100.0%	17,061	95.4%	21,454	98.6%	16,483	99.7%
23	Electronic Enthalpy A (+2)	~75/33	22,101	99.8%	15,543	86.9%	20,263	93.1%	15,934	96.4%
24	Electronic Enthalpy A (-2)	~71/29	22,091	99.8%	17,810	99.6%	21,699	99.7%	16,487	99.7%

Table 10 – Energy Savings for Prototype Building – Climate Zones 5 - 8

			CZ9	CZ10	CZ11	CZ12
	ANNUAL ELECTRICITY USE					
	OA-CONTROL	Setpoint	kWh/yr	kWh/yr	kWh/yr	kWh/yr
Base	FIXED	n/a	440,921	441,855	434,566	426,224
Run 1	FIXED-DB	67	424,367	426,308	421,179	409,314
Run 2	FIXED-DB	69	424,115	426,091	420,951	409,056
Run 3	FIXED-DB	71	423,922	425,868	420,750	408,841
Run 4	FIXED-DB	73	423,986	425,842	420,657	408,793
Run 5	FIXED-DB	75	424,343	425,993	420,664	408,877
Run 6	FIXED-DB	77	425,121	426,366	420,826	409,131
Run 7	DUAL-TEMP	n/a	424,222	425,971	420,647	408,836
Run 8	DUAL-TEMP -4	n/a	425,730	426,697	420,985	409,433
Run 9	DUAL-TEMP +4	n/a	423,944	425,924	420,814	408,933
Run 10	OA-ENTHALPY	28	424,994	427,323	423,856	409,563
Run 11	OA-ENTHALPY	26	426,462	427,896	421,910	409,315
Run 12	OA-ENTHALPY	30	425,624	429,092	427,894	412,424
Run 13	DUAL-ENTHALPY	n/a	424,218	426,134	421,051	408,928
Run 14	DUAL-ENTHALPY + DB HIGH	75	423,981	425,824	420,689	408,758
Run 15	DUAL-ENTHALPY -4	n/a	428,035	431,953	429,370	414,853
Run 16	DUAL ENTHALPY +4	n/a	431,369	432,381	424,774	414,022
Run 17	DUAL-ENTHALPY -4 (+DB)	73	423,986	425,842	420,654	408,793
Run 18	DUAL ENTHALPY +4 (+DB)	77	431,369	432,381	424,774	414,022
Run 19	Dewpoint + DB	55+75	427,925	429,271	421,275	409,911
Run 20	Dewpoint(-5) + DB	50+73	431,076	433,052	423,050	415,323
Run 21	Dewpoint(+5) + DB	60+77	425,458	426,483	420,865	409,118
Run 22	Electronic Enthalpy A	~73/31	423,942	425,830	420,654	408,793
Run 23	Electronic Enthalpy A (+2)	~75/33	424,343	425,993	420,664	408,877
Run 24	Electronic Enthalpy A (-2)	~71/29	423,967	425,875	420,766	408,841

	SAVINGS COMPARED TO NO ECONOMIZ		CZ9		CZ10		CZ11		CZ12	
Run	OA-CONTROL	Setpoint	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max
1	FIXED-DB	67	16,554	**97.4%**	15,547	**97.0%**	13,387	**96.2%**	16,910	**96.8%**
2	FIXED-DB	69	16,806	**98.9%**	15,764	**98.3%**	13,615	**97.8%**	17,168	**98.3%**
3	FIXED-DB	71	16,999	**100.0%**	15,987	**99.7%**	13,816	**99.3%**	17,383	**99.5%**
4	FIXED-DB	73	16,935	**99.6%**	16,013	**99.9%**	13,909	**99.9%**	17,431	**99.8%**
5	FIXED-DB	75	16,578	**97.5%**	15,862	**98.9%**	13,902	**99.9%**	17,347	**99.3%**
6	FIXED-DB	77	15,800	**92.9%**	15,489	**96.6%**	13,740	**98.7%**	17,093	**97.9%**
7	DUAL-TEMP	n/a	16,699	**98.2%**	15,884	**99.1%**	13,919	**100.0%**	17,388	**99.6%**
8	DUAL-TEMP -4	n/a	15,191	**89.4%**	15,158	**94.6%**	13,581	**97.6%**	16,791	**96.1%**
9	DUAL-TEMP +4	n/a	16,977	**99.9%**	15,931	**99.4%**	13,752	**98.8%**	17,291	**99.0%**
10	OA-ENTHALPY	28	15,927	**93.7%**	14,532	**90.6%**	10,710	**76.9%**	16,661	**95.4%**
11	OA-ENTHALPY	26	14,459	**85.1%**	13,959	**87.1%**	12,656	**90.9%**	16,909	**96.8%**
12	OA-ENTHALPY	30	15,297	**90.0%**	12,763	**79.6%**	6,672	**47.9%**	13,800	**79.0%**
13	DUAL-ENTHALPY	n/a	16,703	**98.3%**	15,721	**98.1%**	13,515	**97.1%**	17,296	**99.0%**
14	DUAL-ENTHALPY + DB HIGH	varies	16,942	**99.7%**	16,031	**100.0%**	13,877	**99.7%**	17,466	**100.0%**
15	DUAL-ENTHALPY -4	n/a	12,886	**75.8%**	9,902	**61.8%**	5,196	**37.3%**	11,371	**65.1%**
16	DUAL ENTHALPY +4	n/a	9,552	**56.2%**	9,474	**59.1%**	9,792	**70.3%**	12,202	**69.9%**
17	DUAL-ENTHALPY -4 (+DB)	73	16,935	**99.6%**	16,013	**99.9%**	13,912	**99.9%**	17,431	**99.8%**
18	DUAL ENTHALPY +4 (+DB)	77	9,552	**56.2%**	9,474	**59.1%**	9,792	**70.3%**	12,202	**69.9%**
19	Dewpoint + DB	55+75	12,996	**76.5%**	12,584	**78.5%**	13,291	**95.5%**	16,313	**93.4%**
20	Dewpoint(-5) + DB	50+73	9,845	**57.9%**	8,803	**54.9%**	11,516	**82.7%**	10,901	**62.4%**
21	Dewpoint(+5) + DB	60+77	15,463	**91.0%**	15,372	**95.9%**	13,701	**98.4%**	17,106	**97.9%**
22	Electronic Enthalpy A	~73/31	16,979	**99.9%**	16,025	**100.0%**	13,912	**99.9%**	17,431	**99.8%**
23	Electronic Enthalpy A (+2)	~75/33	16,578	**97.5%**	15,862	**98.9%**	13,902	**99.9%**	17,347	**99.3%**
24	Electronic Enthalpy A (-2)	~71/29	16,954	**99.7%**	15,980	**99.7%**	13,800	**99.1%**	17,383	**99.5%**

Table 11 – Energy Savings for Prototype Building – Climate Zones 9 - 12

	ANNUAL ELECTRICITY USE		CZ13	CZ14	CZ15	CZ16
	OA-CONTROL	Setpoint	kWh/yr	kWh/yr	kWh/yr	kWh/yr
Base	FIXED	n/a	442,410	437,822	489,883	399,266
Run 1	FIXED-DB	67	428,388	424,811	481,238	387,666
Run 2	FIXED-DB	69	428,010	424,685	481,037	387,379
Run 3	FIXED-DB	71	427,762	424,515	480,752	387,111
Run 4	FIXED-DB	73	427,621	424,389	480,528	386,945
Run 5	FIXED-DB	75	427,679	424,368	480,514	386,898
Run 6	FIXED-DB	77	427,888	424,475	480,655	387,039
Run 7	DUAL-TEMP	n/a	427,651	424,361	480,493	386,891
Run 8	DUAL-TEMP -4	n/a	428,206	424,553	480,883	387,229
Run 9	DUAL-TEMP +4	n/a	427,847	424,565	480,809	387,184
Run 10	OA-ENTHALPY	28	428,867	429,353	487,110	387,606
Run 11	OA-ENTHALPY	26	428,309	426,273	484,185	387,491
Run 12	OA-ENTHALPY	30	432,000	433,281	491,165	387,775
Run 13	DUAL-ENTHALPY	n/a	427,877	425,112	481,470	387,261
Run 14	DUAL-ENTHALPY + DB HIGH	75	427,608	424,377	480,532	386,919
Run 15	DUAL-ENTHALPY -4	n/a	435,249	433,344	491,972	388,047
Run 16	DUAL ENTHALPY +4	n/a	431,783	427,396	483,834	389,131
Run 17	DUAL-ENTHALPY -4 (+DB)	73	427,621	424,389	480,528	386,945
Run 18	DUAL ENTHALPY +4 (+DB)	77	431,783	427,390	483,834	389,128
Run 19	Dewpoint + DB	55+75	428,166	424,607	480,640	386,983
Run 20	Dewpoint(-5) + DB	50+73	430,928	425,499	481,414	387,424
Run 21	Dewpoint(+5) + DB	60+77	427,801	424,493	480,669	386,978
Run 22	Electronic Enthalpy A	~73/31	427,621	424,389	480,528	386,945
Run 23	Electronic Enthalpy A (+2)	~75/33	427,679	424,368	480,514	386,898
Run 24	Electronic Enthalpy A (-2)	~71/29	427,763	424,515	480,751	387,111

	SAVINGS COMPARED TO NO ECONOMI		CZ13		CZ14		CZ15		CZ16	
Run	OA-CONTROL	Setpoint	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max	kWh/yr	% of Max
1	FIXED-DB	67	14,022	94.7%	13,011	96.7%	8,645	92.1%	11,600	93.7%
2	FIXED-DB	69	14,400	97.3%	13,137	97.6%	8,846	94.2%	11,887	96.1%
3	FIXED-DB	71	14,648	99.0%	13,307	98.9%	9,131	97.2%	12,155	98.2%
4	FIXED-DB	73	14,789	99.9%	13,433	99.8%	9,355	99.6%	12,321	99.6%
5	FIXED-DB	75	14,731	99.5%	13,454	99.9%	9,369	99.8%	12,368	99.9%
6	FIXED-DB	77	14,522	98.1%	13,347	99.2%	9,228	98.3%	12,227	98.8%
7	DUAL-TEMP	n/a	14,759	99.7%	13,461	100.0%	9,390	100.0%	12,375	100.0%
8	DUAL-TEMP -4	n/a	14,204	96.0%	13,269	98.6%	9,000	95.8%	12,037	97.3%
9	DUAL-TEMP +4	n/a	14,563	98.4%	13,257	98.5%	9,074	96.6%	12,082	97.6%
10	OA-ENTHALPY	28	13,543	91.5%	8,469	62.9%	2,773	29.5%	11,660	94.2%
11	OA-ENTHALPY	26	14,101	95.3%	11,549	85.8%	5,698	60.7%	11,775	95.2%
12	OA-ENTHALPY	30	10,410	70.3%	4,541	33.7%	-1,282	-13.7%	11,491	92.9%
13	DUAL-ENTHALPY	n/a	14,533	98.2%	12,710	94.4%	8,413	89.6%	12,005	97.0%
14	DUAL-ENTHALPY + DB HIGH	varies	14,802	100.0%	13,448	99.9%	9,365	99.7%	12,347	99.8%
15	DUAL-ENTHALPY -4	n/a	7,161	48.4%	4,478	33.3%	-2,089	-22.2%	11,219	90.7%
16	DUAL ENTHALPY +4	n/a	10,627	71.8%	10,426	77.5%	6,049	64.4%	10,135	81.9%
17	DUAL-ENTHALPY -4 (+DB)	73	14,789	99.9%	13,433	99.8%	9,355	99.6%	12,321	99.6%
18	DUAL ENTHALPY +4 (+DB)	77	10,627	71.8%	10,432	77.5%	6,049	64.4%	10,138	81.9%
19	Dewpoint + DB	55+75	14,244	96.2%	13,215	98.2%	9,243	98.4%	12,283	99.3%
20	Dewpoint(-5) + DB	50+73	11,482	77.6%	12,323	91.5%	8,469	90.2%	11,842	95.7%
21	Dewpoint(+5) + DB	60+77	14,609	98.7%	13,329	99.0%	9,214	98.1%	12,288	99.3%
22	Electronic Enthalpy A	~73/31	14,789	99.9%	13,433	99.8%	9,355	99.6%	12,321	99.6%
23	Electronic Enthalpy A (+2)	~75/33	14,731	99.5%	13,454	99.9%	9,369	99.8%	12,368	99.9%
24	Electronic Enthalpy A (-2)	~71/29	14,647	99.0%	13,307	98.9%	9,132	97.3%	12,155	98.2%

Table 12 – Energy Savings for Prototype Building – Climate Zones 13 - 16

		CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9
		SAVINGS COMPARED TO NO ECONOMIZER (kWh/sf/yr)								
OA-CONTROL	Setpoint	Total	Total	Total	Total	Total	Total	Total	Total	Total
FIXED-DB	67	0.642	0.465	0.593	0.473	0.537	0.434	0.534	0.398	0.414
FIXED-DB	69	0.642	0.471	0.599	0.481	0.547	0.445	0.544	0.406	0.420
FIXED-DB	71	0.642	0.476	0.604	0.486	0.552	0.446	0.538	0.413	0.425
FIXED-DB	73	0.642	0.477	0.605	0.489	0.554	0.420	0.515	0.411	0.423
FIXED-DB	75	0.642	0.476	0.604	0.486	0.553	0.388	0.498	0.398	0.414
FIXED-DB	77	0.642	0.470	0.603	0.478	0.550	0.363	0.490	0.381	0.395
Diff DB	n/a	0.642	0.477	0.604	0.488	0.553	0.399	0.502	0.399	0.417
DUAL-TEMP -4	n/a	0.642	0.463	0.601	0.470	0.549	0.352	0.487	0.359	0.380
DUAL-TEMP +4	n/a	0.642	0.474	0.604	0.483	0.550	0.447	0.543	0.412	0.424
Fixed Enthalpy	28	0.642	0.458	0.602	0.478	0.548	0.428	0.530	0.388	0.398
OA-ENTHALPY	26	0.638	0.467	0.594	0.475	0.538	0.363	0.482	0.351	0.361
OA-ENTHALPY	30	0.642	0.413	0.590	0.434	0.543	0.423	0.541	0.382	0.382
Diff Enthalpy	n/a	0.642	0.476	0.605	0.487	0.552	0.442	0.535	0.402	0.418
Diff Enthalpy + DB	varies	0.642	0.478	0.605	0.489	0.553	0.444	0.536	0.407	0.424
DUAL-ENTHALPY -4	n/a	0.642	0.388	0.589	0.397	0.542	0.357	0.497	0.307	0.322
DUAL ENTHALPY +4	n/a	0.570	0.375	0.425	0.324	0.397	0.202	0.245	0.197	0.239
DUAL-ENTHALPY -4 (+DB)	73	0.642	0.477	0.605	0.489	0.554	0.420	0.517	0.411	0.423
DUAL ENTHALPY +4 (+DB)	77	0.570	0.375	0.425	0.324	0.397	0.202	0.245	0.197	0.239
DP + DB	55+75	0.596	0.457	0.537	0.440	0.510	0.296	0.406	0.303	0.325
Dewpoint(-5) + DB	50+73	0.311	0.318	0.304	0.279	0.287	0.166	0.236	0.206	0.246
Dewpoint(+5) + DB	60+77	0.640	0.470	0.603	0.479	0.551	0.399	0.523	0.380	0.387
Fixed Enthalpy + DB	~73/31	0.642	0.477	0.605	0.489	0.554	0.427	0.536	0.412	0.424
Electronic Enthalpy A (+2)	~75/33	0.642	0.476	0.604	0.486	0.553	0.389	0.507	0.398	0.414
Electronic Enthalpy A (-2)	~71/29	0.642	0.476	0.604	0.486	0.552	0.445	0.542	0.412	0.424

	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
	SAVINGS COMPARED TO NO ECONOMIZER (kWh/sf/yr)						
OA-CONTROL	Total	Total	Total	Total	Total	Total	Total
FIXED-DB	0.389	0.335	0.423	0.351	0.325	0.216	0.290
FIXED-DB	0.394	0.340	0.429	0.360	0.328	0.221	0.297
FIXED-DB	0.400	0.345	0.435	0.366	0.333	0.228	0.304
FIXED-DB	0.400	0.348	0.436	0.370	0.336	0.234	0.308
FIXED-DB	0.397	0.348	0.434	0.368	0.336	0.234	0.309
FIXED-DB	0.387	0.344	0.427	0.363	0.334	0.231	0.306
Diff DB	0.397	0.348	0.435	0.369	0.337	0.235	0.309
DUAL-TEMP -4	0.379	0.340	0.420	0.355	0.332	0.225	0.301
DUAL-TEMP +4	0.398	0.344	0.432	0.364	0.331	0.227	0.302
Fixed Enthalpy	0.363	0.268	0.417	0.339	0.212	0.069	0.292
OA-ENTHALPY	0.349	0.316	0.423	0.353	0.289	0.142	0.294
OA-ENTHALPY	0.319	0.167	0.345	0.260	0.114	-0.032	0.287
Diff Enthalpy	0.393	0.338	0.432	0.363	0.318	0.210	0.300
Diff Enthalpy + DB	0.401	0.347	0.437	0.370	0.336	0.234	0.309
DUAL-ENTHALPY -4	0.248	0.130	0.284	0.179	0.112	-0.052	0.280
DUAL ENTHALPY +4	0.237	0.245	0.305	0.266	0.261	0.151	0.253
DUAL-ENTHALPY -4 (+DB)	0.400	0.348	0.436	0.370	0.336	0.234	0.308
DUAL ENTHALPY +4 (+DB)	0.237	0.245	0.305	0.266	0.261	0.151	0.253
DP + DB	0.315	0.332	0.408	0.356	0.330	0.231	0.307
Dewpoint(-5) + DB	0.220	0.288	0.273	0.287	0.308	0.212	0.296
Dewpoint(+5) + DB	0.384	0.343	0.428	0.365	0.333	0.230	0.307
Fixed Enthalpy + DB	0.401	0.348	0.436	0.370	0.336	0.234	0.308
Electronic Enthalpy A (+2)	0.397	0.348	0.434	0.368	0.336	0.234	0.309
Electronic Enthalpy A (-2)	0.400	0.345	0.435	0.366	0.333	0.228	0.304

Table 13 – Energy Savings per Square Foot for Prototype Building

	PEAK DEMAND (kW)		CZ1	CZ2	CZ3	CZ4
	OA-CONTROL	Setpoint	Total	Total	Total	Total
Base	FIXED	n/a	137	150	136	140
Run 1	FIXED-DB	67	118	147	126	135
Run 2	FIXED-DB	69	118	147	126	135
Run 3	FIXED-DB	71	118	147	126	135
Run 4	FIXED-DB	73	118	147	126	135
Run 5	FIXED-DB	75	119	147	126	135
Run 6	FIXED-DB	77	119	147	127	135
Run 7	DUAL-TEMP	n/a	118	147	126	135
Run 8	DUAL-TEMP -4	n/a	119	147	134	135
Run 9	DUAL-TEMP +4	n/a	118	147	126	135
Run 10	OA-ENTHALPY	28	119	147	133	140
Run 11	OA-ENTHALPY	26	118	147	128	135
Run 12	OA-ENTHALPY	30	124	155	140	142
Run 13	DUAL-ENTHALPY	n/a	118	147	126	135
Run 14	DUAL-ENTHALPY + DB HIGH	75	118	147	126	135
Run 15	DUAL-ENTHALPY -4	n/a	124	149	141	145
Run 16	DUAL ENTHALPY +4	n/a	118	147	126	135
Run 17	DUAL-ENTHALPY -4 (+DB)	73	118	147	126	135
Run 18	DUAL ENTHALPY +4 (+DB)	77	118	147	126	135
Run 19	Dewpoint + DB	55+75	118	147	126	135
Run 20	Dewpoint(-5) + DB	50+73	118	147	126	135
Run 21	Dewpoint(+5) + DB	60+77	119	147	127	135
Run 22	Electronic Enthalpy A	~73/31	118	147	126	135
Run 23	Electronic Enthalpy A (+2)	~75/33	119	147	126	135
Run 24	Electronic Enthalpy A (-2)	~71/29	118	147	126	135

	SAVINGS COMPARED TO NO ECONOMIZER		CZ1		CZ2		CZ3		CZ4	
Run	OA-CONTROL	Setpoint	kW	W/sf	kW	MWh/yr	kW	MWh/yr	kW	MWh/yr
1	FIXED-DB	67	19	0.474	4	0.092	10	0.241	5	0.125
2	FIXED-DB	69	19	0.474	4	0.092	10	0.241	5	0.125
3	FIXED-DB	71	19	0.474	4	0.092	10	0.241	5	0.125
4	FIXED-DB	73	19	0.474	4	0.092	10	0.241	5	0.125
5	FIXED-DB	75	18	0.456	4	0.092	10	0.241	5	0.125
6	FIXED-DB	77	18	0.456	4	0.092	9	0.223	5	0.122
7	DUAL-TEMP	n/a	19	0.474	4	0.092	10	0.241	5	0.125
8	DUAL-TEMP -4	n/a	18	0.456	4	0.092	1	0.037	5	0.122
9	DUAL-TEMP +4	n/a	19	0.474	4	0.092	10	0.241	5	0.125
10	OA-ENTHALPY	28	18	0.446	3	0.086	3	0.082	0	-0.012
11	OA-ENTHALPY	26	19	0.474	4	0.092	8	0.194	5	0.125
12	OA-ENTHALPY	30	13	0.319	-4	-0.111	-4	-0.111	-2	-0.055
13	DUAL-ENTHALPY	n/a	19	0.474	4	0.092	10	0.241	5	0.125
14	DUAL-ENTHALPY + DB HIGH	varies	19	0.474	4	0.092	10	0.241	5	0.125
15	DUAL-ENTHALPY -4	n/a	13	0.319	1	0.034	-5	-0.115	-5	-0.136
16	DUAL ENTHALPY +4	n/a	19	0.474	4	0.092	10	0.241	5	0.125
17	DUAL-ENTHALPY -4 (+DB)	73	19	0.474	4	0.092	10	0.241	5	0.125
18	DUAL ENTHALPY +4 (+DB)	77	19	0.474	4	0.092	10	0.241	5	0.125
19	Dewpoint + DB	55+75	19	0.474	4	0.092	10	0.241	5	0.125
20	Dewpoint(-5) + DB	50+73	19	0.474	4	0.092	10	0.241	5	0.125
21	Dewpoint(+5) + DB	60+77	18	0.456	4	0.092	9	0.219	5	0.125
22	Electronic Enthalpy A	~73/31	19	0.474	4	0.092	10	0.241	5	0.125
23	Electronic Enthalpy A (+2)	~75/33	18	0.456	4	0.092	10	0.241	5	0.125
24	Electronic Enthalpy A (-2)	~71/29	19	0.474	4	0.092	10	0.241	5	0.125

Table 14 – Peak Demand Savings for Prototype Building – Climate Zones 1 - 4

	PEAK DEMAND (kW)		CZ5	CZ6	CZ7	CZ8
	OA-CONTROL	Setpoint	Total	Total	Total	Total
Base	FIXED	n/a	133	132	127	134
Run 1	FIXED-DB	67	120	131	127	134
Run 2	FIXED-DB	69	120	131	127	134
Run 3	FIXED-DB	71	120	131	130	134
Run 4	FIXED-DB	73	120	136	138	134
Run 5	FIXED-DB	75	124	139	148	137
Run 6	FIXED-DB	77	127	143	148	137
Run 7	DUAL-TEMP	n/a	124	137	144	137
Run 8	DUAL-TEMP -4	n/a	130	147	151	139
Run 9	DUAL-TEMP +4	n/a	120	131	127	134
Run 10	OA-ENTHALPY	28	133	139	127	140
Run 11	OA-ENTHALPY	26	133	131	127	140
Run 12	OA-ENTHALPY	30	133	139	128	150
Run 13	DUAL-ENTHALPY	n/a	122	131	127	134
Run 14	DUAL-ENTHALPY + DB HIGH	75	120	131	127	134
Run 15	DUAL-ENTHALPY -4	n/a	133	140	139	145
Run 16	DUAL ENTHALPY +4	n/a	120	131	127	134
Run 17	DUAL-ENTHALPY -4 (+DB)	73	120	136	137	134
Run 18	DUAL ENTHALPY +4 (+DB)	77	120	131	127	134
Run 19	Dewpoint + DB	55+75	120	131	127	134
Run 20	Dewpoint(-5) + DB	50+73	120	131	127	134
Run 21	Dewpoint(+5) + DB	60+77	125	133	127	134
Run 22	Electronic Enthalpy A	~73/31	120	132	129	134
Run 23	Electronic Enthalpy A (+2)	~75/33	124	139	138	137
Run 24	Electronic Enthalpy A (-2)	~71/29	120	131	127	134

	SAVINGS COMPARED TO NO ECONOMIZER		CZ5		CZ6		CZ7		CZ8	
Run	OA-CONTROL	Setpoint	kW	W/sf	kW	MWh/yr	kW	W/sf	kW	MWh/yr
1	FIXED-DB	67	13	0.336	1	0.021	0	0.000	0	0.000
2	FIXED-DB	69	13	0.336	1	0.021	0	0.000	0	0.000
3	FIXED-DB	71	13	0.336	1	0.021	-3	-0.065	0	0.000
4	FIXED-DB	73	13	0.336	-5	-0.115	-11	-0.284	0	0.000
5	FIXED-DB	75	10	0.239	-7	-0.176	-21	-0.522	-4	-0.089
6	FIXED-DB	77	6	0.146	-12	-0.289	-21	-0.522	-3	-0.066
7	DUAL-TEMP	n/a	10	0.242	-5	-0.128	-17	-0.427	-4	-0.089
8	DUAL-TEMP -4	n/a	3	0.079	-16	-0.393	-24	-0.590	-5	-0.119
9	DUAL-TEMP +4	n/a	13	0.336	1	0.021	0	0.000	0	0.000
10	OA-ENTHALPY	28	1	0.020	-7	-0.171	0	0.000	-6	-0.150
11	OA-ENTHALPY	26	1	0.020	1	0.021	0	0.000	-6	-0.150
12	OA-ENTHALPY	30	1	0.020	-7	-0.171	-1	-0.015	-16	-0.408
13	DUAL-ENTHALPY	n/a	11	0.277	1	0.021	0	0.000	0	0.000
14	DUAL-ENTHALPY + DB HIGH	varies	13	0.336	1	0.021	0	0.000	0	0.000
15	DUAL-ENTHALPY -4	n/a	1	0.014	-8	-0.204	-12	-0.304	-11	-0.270
16	DUAL ENTHALPY +4	n/a	13	0.336	1	0.021	0	0.000	0	0.000
17	DUAL-ENTHALPY -4 (+DB)	73	13	0.336	-5	-0.115	-10	-0.251	0	0.000
18	DUAL ENTHALPY +4 (+DB)	77	13	0.336	1	0.021	0	0.000	0	0.000
19	Dewpoint + DB	55+75	13	0.336	1	0.021	0	0.000	0	0.000
20	Dewpoint(-5) + DB	50+73	13	0.336	1	0.021	0	0.000	0	0.000
21	Dewpoint(+5) + DB	60+77	8	0.212	-2	-0.045	0	0.000	0	0.000
22	Electronic Enthalpy A	~73/31	13	0.336	-1	-0.018	-2	-0.061	0	0.000
23	Electronic Enthalpy A (+2)	~75/33	10	0.239	-7	-0.176	-11	-0.271	-4	-0.089
24	Electronic Enthalpy A (-2)	~71/29	13	0.336	1	0.021	0	0.000	0	0.000

Table 15 – Peak Demand Savings for Prototype Building – Climate Zones 5 - 8

	PEAK DEMAND (kW)		CZ9	CZ10	CZ11	CZ12
	OA-CONTROL	Setpoint	Total	Total	Total	Total
Base	FIXED	n/a	146	145	145	149
Run 1	FIXED-DB	67	146	145	145	149
Run 2	FIXED-DB	69	146	145	145	149
Run 3	FIXED-DB	71	146	145	145	149
Run 4	FIXED-DB	73	146	145	145	149
Run 5	FIXED-DB	75	146	145	145	149
Run 6	FIXED-DB	77	146	145	145	149
Run 7	DUAL-TEMP	n/a	146	145	145	149
Run 8	DUAL-TEMP -4	n/a	146	145	145	149
Run 9	DUAL-TEMP +4	n/a	146	145	145	149
Run 10	OA-ENTHALPY	28	146	149	154	149
Run 11	OA-ENTHALPY	26	146	145	145	149
Run 12	OA-ENTHALPY	30	146	150	158	154
Run 13	DUAL-ENTHALPY	n/a	146	145	145	149
Run 14	DUAL-ENTHALPY + DB HIGH	75	146	145	145	149
Run 15	DUAL-ENTHALPY -4	n/a	147	152	157	154
Run 16	DUAL ENTHALPY +4	n/a	146	145	145	149
Run 17	DUAL-ENTHALPY -4 (+DB)	73	146	145	145	149
Run 18	DUAL ENTHALPY +4 (+DB)	77	146	145	145	149
Run 19	Dewpoint + DB	55+75	146	145	145	149
Run 20	Dewpoint(-5) + DB	50+73	146	145	145	149
Run 21	Dewpoint(+5) + DB	60+77	146	145	145	149
Run 22	Electronic Enthalpy A	~73/31	146	145	145	149
Run 23	Electronic Enthalpy A (+2)	~75/33	146	145	145	149
Run 24	Electronic Enthalpy A (-2)	~71/29	146	145	145	149

	SAVINGS COMPARED TO NO ECONOMIZER		CZ9		CZ10		CZ11		CZ12	
Run	OA-CONTROL	Setpoint	kW	W/sf	kW	MWh/yr	kW	W/sf	kW	MWh/yr
1	FIXED-DB	67	0	0.000	0	0.000	0	0.000	0	0.001
2	FIXED-DB	69	0	0.000	0	0.000	0	0.000	0	0.001
3	FIXED-DB	71	0	0.000	0	0.000	0	0.000	0	0.001
4	FIXED-DB	73	0	0.000	0	0.000	0	0.000	0	0.001
5	FIXED-DB	75	0	0.000	0	0.000	0	0.000	0	0.001
6	FIXED-DB	77	0	0.000	0	0.000	0	0.000	0	0.001
7	DUAL-TEMP	n/a	0	0.000	0	0.000	0	0.000	0	0.001
8	DUAL-TEMP -4	n/a	0	0.000	0	0.000	0	0.000	0	0.001
9	DUAL-TEMP +4	n/a	0	0.000	0	0.000	0	0.000	0	0.001
10	OA-ENTHALPY	28	0	0.000	-4	-0.107	-9	-0.229	0	0.001
11	OA-ENTHALPY	26	0	0.000	0	0.000	0	0.000	0	0.001
12	OA-ENTHALPY	30	0	0.000	-5	-0.132	-13	-0.327	-5	-0.124
13	DUAL-ENTHALPY	n/a	0	0.000	0	0.000	0	0.000	0	0.001
14	DUAL-ENTHALPY + DB HIGH	varies	0	0.000	0	0.000	0	0.000	0	0.001
15	DUAL-ENTHALPY -4	n/a	0	-0.008	-7	-0.178	-12	-0.295	-6	-0.139
16	DUAL ENTHALPY +4	n/a	0	0.000	0	0.000	0	0.000	0	0.001
17	DUAL-ENTHALPY -4 (+DB)	73	0	0.000	0	0.000	0	0.000	0	0.001
18	DUAL ENTHALPY +4 (+DB)	77	0	0.000	0	0.000	0	0.000	0	0.001
19	Dewpoint + DB	55+75	0	0.000	0	0.000	0	0.000	0	0.001
20	Dewpoint(-5) + DB	50+73	0	0.000	0	0.000	0	0.000	0	0.001
21	Dewpoint(+5) + DB	60+77	0	0.000	0	0.000	0	0.000	0	0.001
22	Electronic Enthalpy A	~73/31	0	0.000	0	0.000	0	0.000	0	0.001
23	Electronic Enthalpy A (+2)	~75/33	0	0.000	0	0.000	0	0.000	0	0.001
24	Electronic Enthalpy A (-2)	~71/29	0	0.000	0	0.000	0	0.000	0	0.001

Table 16 – Peak Demand Savings for Prototype Building – Climate Zones 9 - 12

	PEAK DEMAND (kW)		CZ13	CZ14	CZ15	CZ16
	OA-CONTROL	Setpoint	Total	Total	Total	Total
Base	FIXED	n/a	150	149	155	137
Run 1	FIXED-DB	67	148	149	155	124
Run 2	FIXED-DB	69	148	149	155	124
Run 3	FIXED-DB	71	148	149	155	124
Run 4	FIXED-DB	73	148	149	155	124
Run 5	FIXED-DB	75	148	149	155	124
Run 6	FIXED-DB	77	148	149	155	131
Run 7	DUAL-TEMP	n/a	148	149	155	124
Run 8	DUAL-TEMP -4	n/a	148	149	155	131
Run 9	DUAL-TEMP +4	n/a	148	149	155	124
Run 10	OA-ENTHALPY	28	151	157	157	137
Run 11	OA-ENTHALPY	26	148	149	155	130
Run 12	OA-ENTHALPY	30	155	159	158	140
Run 13	DUAL-ENTHALPY	n/a	148	149	155	134
Run 14	DUAL-ENTHALPY + DB HIGH	75	148	149	155	124
Run 15	DUAL-ENTHALPY -4	n/a	156	157	157	141
Run 16	DUAL ENTHALPY +4	n/a	148	149	155	124
Run 17	DUAL-ENTHALPY -4 (+DB)	73	148	149	155	124
Run 18	DUAL ENTHALPY +4 (+DB)	77	148	149	155	124
Run 19	Dewpoint + DB	55+75	148	149	155	124
Run 20	Dewpoint(-5) + DB	50+73	148	149	155	124
Run 21	Dewpoint(+5) + DB	60+77	148	149	155	124
Run 22	Electronic Enthalpy A	~73/31	148	149	155	124
Run 23	Electronic Enthalpy A (+2)	~75/33	148	149	155	124
Run 24	Electronic Enthalpy A (-2)	~71/29	148	149	155	124

	SAVINGS COMPARED TO NO ECONOMIZER		CZ13		CZ14		CZ15		CZ16	
Run	OA-CONTROL	Setpoint	kW	W/sf	kW	MWh/yr	kW	W/sf	kW	MWh/yr
1	FIXED-DB	67	2	0.055	0	0.000	0	0.000	13	0.315
2	FIXED-DB	69	2	0.055	0	0.000	0	0.000	13	0.315
3	FIXED-DB	71	2	0.055	0	0.000	0	0.000	13	0.315
4	FIXED-DB	73	2	0.055	0	0.000	0	0.000	13	0.315
5	FIXED-DB	75	2	0.055	0	0.000	0	0.000	13	0.315
6	FIXED-DB	77	2	0.055	0	0.000	0	0.000	6	0.139
7	DUAL-TEMP	n/a	2	0.055	0	0.000	0	0.000	13	0.315
8	DUAL-TEMP -4	n/a	2	0.055	0	0.000	0	0.000	6	0.139
9	DUAL-TEMP +4	n/a	2	0.055	0	0.000	0	0.000	13	0.315
10	OA-ENTHALPY	28	0	-0.011	-8	-0.188	-2	-0.048	0	0.010
11	OA-ENTHALPY	26	2	0.055	0	0.000	0	0.000	7	0.183
12	OA-ENTHALPY	30	-5	-0.129	-9	-0.237	-3	-0.084	-3	-0.066
13	DUAL-ENTHALPY	n/a	2	0.055	0	0.000	0	0.000	3	0.079
14	DUAL-ENTHALPY + DB HIGH	varies	2	0.055	0	0.000	0	0.000	13	0.315
15	DUAL-ENTHALPY -4	n/a	-6	-0.150	-8	-0.198	-2	-0.062	-4	-0.095
16	DUAL ENTHALPY +4	n/a	2	0.055	0	0.000	0	0.000	13	0.315
17	DUAL-ENTHALPY -4 (+DB)	73	2	0.055	0	0.000	0	0.000	13	0.315
18	DUAL ENTHALPY +4 (+DB)	77	2	0.055	0	0.000	0	0.000	13	0.315
19	Dewpoint + DB	55+75	2	0.055	0	0.000	0	0.000	13	0.315
20	Dewpoint(-5) + DB	50+73	2	0.055	0	0.000	0	0.000	13	0.315
21	Dewpoint(+5) + DB	60+77	2	0.055	0	0.000	0	0.000	13	0.315
22	Electronic Enthalpy A	~73/31	2	0.055	0	0.000	0	0.000	13	0.315
23	Electronic Enthalpy A (+2)	~75/33	2	0.055	0	0.000	0	0.000	13	0.315
24	Electronic Enthalpy A (-2)	~71/29	2	0.055	0	0.000	0	0.000	13	0.315

Table 17 – Peak Demand Savings for Prototype Building – Climate Zones 13 - 16

Appendix M: Endnotes

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